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ACETYLENE GAS:

ITS PRODUCTION AND USE.

W. DOMAN.

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THE PRODUCTION
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THE PRODUCTION AND USE

OF

ACETYLENE GAS.

BY

W. DOMAN.

WITH THIRTY ILLUSTRATIONS.

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PREFACE.

THIS handbook was written in the form of monthly articles for THE ENGINEERING TIMES in response to the desire for a practical work on Acetylene Engineering, evinced not only by those connected with the trade, but also by the country ironmongers and gasfitters, as well as purchasers of large plants.

I have left entirely unnoticed all apparatus that is in any way unsound in principle, and endeavour to illustrate only such as are likely to stand the test of time. The chapter on Generator Design was practically written some time ago, since when the whole tendency of the trade has been to confirm the opinion that the simple forms there illustrated are those which will continue when the more complicated and intricate productions of the inventor or ingenious mechanic are departed.

The desire for a small "automatic" generator is steadily giving place to an appreciation of the advantages of the large gasholder, an acquaintance with which is gradually educating the apparatus makers up to the knowledge that the efficient automatic generator is only an exactly similar apparatus to the non-automatic that cuts off the supply of water when the holder rises (or feeds in carbide when it falls).

Looking at it from this point of view, the tendency to ingenious and intricate mechanism is checked, and the attention of the manufacturer or inventor is free to apply itself to the one important point in all plants, that of the production of gas at the lowest possible temperature in the generating chamber.

Appreciation of the light is steadily gaining ground, and the public is becoming aware that the difficulties and dangers imagined at first are non-existent. It now only remains for the makers to set their houses in order, discard some of their cherished patents, and pay more attention to the theory of the subject.

The position and difficulties of the acetylene industry are often likened to those of electric lighting in its early stages. While indicating that nearly all new industries pass through a period of empiricism and quackery, the parallel hardly goes farther.

Electricity had a long incubation and infancy, while acetylene lighting was born comparatively full-grown, and is probably subject to far more virulent forms of the disorders attending youth. It is perhaps also to be expected that these will have a correspondingly short course.

The lately-formed Acetylene Association should have a very beneficial influence on the trade by bringing about an interchange of opinions, and impressing upon the members the requirements of the industry as a whole. It is to be hoped at the same time that there will be an entire absence of any attempt at the grandmotherly interference seen in many foreign associations.

W. Doman

London,
February, 1902.

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THE
PRODUCTION AND USE OF ACETYLENE GAS.

CHAPTER I.

THE intention of this work is to develop the practical rather than the theoretical part of the subject, to place the reader in a position to make choice of the most satisfactory method of producing and using acetylene, and to enable him to design and erect the necessary plant for this purpose.

Although, at the present time, the most up-to-date apparatus leaves but little to be desired in the way of simplicity and effectiveness, it is hardly likely that our present methods are incapable of radical changes; but they undoubtedly show sufficient evidence of permanency to deserve the close attention both of the practical man and the student.

The advantages and uses of acetylene lighting, regulations as to storage and carriage of carbide, and a short description of its manufacture are included, to make the general usefulness of these papers as complete as possible.

The chemistry of acetylene has been but lightly touched upon, and the student is referred for fuller information to Prof. Lewes' work, to which I am mainly indebted for the figures and facts relating to this part of the subject.

For the greater portion of the following section on carbide I am indebted to Mr. Chas. Bingham, who has very kindly placed at my disposal a paper written by him on this subject.

I.—CARBIDE OF CALCIUM.

Up to the present time the honour of having discovered calcium carbide (carbide of calcium or calcic carbide, as it is often called) has been attributed to the German chemist Wöhler, the French chemist Moissan, and the Canadian engineer Willson.

Wöhler prepared carbide as early as 1862, but his process produced only an impure compound; and as he made no use of electricity, his discovery has proved of little value for present-day practice.

Moissan, however, may fairly claim to be the father of the calcium carbide industry, at any rate in Europe. His descriptions of the process to be employed to produce carbide in the electric furnace, which he first began to publish in 1892, and his beautifully complete investigations of its properties, still form the most exhaustive original work we possess on the subject.

To the Canadian Willson, also, a meed of praise must be awarded. While endeavouring to prepare metallic calcium in the electric furnace, in 1892, he accidentally obtained calcium carbide. With the shrewdness characteristic of his continent, he saw that a substance which could apparently be so easily prepared, and yielded an illuminating gas by simple contact with water, should have a brilliant commercial future before it; and with great tenacity he continued his experiments, with a view to production on a commercial scale. It was, however, not until some months after Moissan communicated his celebrated 1894 paper to the world, through the *Comptes Rendus*, that Willson filed his 1894 patents, which constitute his strongest claim to be one of the first discoverers of commercial carbide.

Investigations carried out by the writer some months back, in connection with a patent case, show, however, in the clearest way, that the honour of first discovery does not rest with either Wöhler, Moissan, or Willson, but with an American scientist, Dr. Robert Hare, of Philadelphia.

Dr. Hare, who appears, taking the cruder electrical appliances at his disposal into consideration, to have been as indefatigable an investigator as Moissan, read in 1839 and 1840 several papers, which are published in *The American Journal of Science*, on the production of "carburet" (as "carbide" was then called) of calcium, and described a method of making it, by subjecting a mixture of quicklime and carbonaceous matter, placed on the bottom electrode of an electric furnace, and immediately below the upper electrode, to the heat produced by passing the current from 200 large Cruikshank cells through it; or, in other words, by subjecting the mixture to the heat of the electric arc.

Dr. Hare describes the product obtained, and states in his communications that it oxydized in the air, and that when brought into contact with water it gave off an "odorous" gas. He did not, however, realize the value of the product he had discovered, nor would he have been able to make much use of it, even had he known its value, as the cheap current of the dynamo was not at that time available.

In May, 1895, the Acetylene Illuminating Company put up a small plant at Leeds, with steam power for making carbide commercially; the Electro-Chemical works at Bitterfeld commenced to supply carbide in February, 1895, thus about the same time, on the Continent.

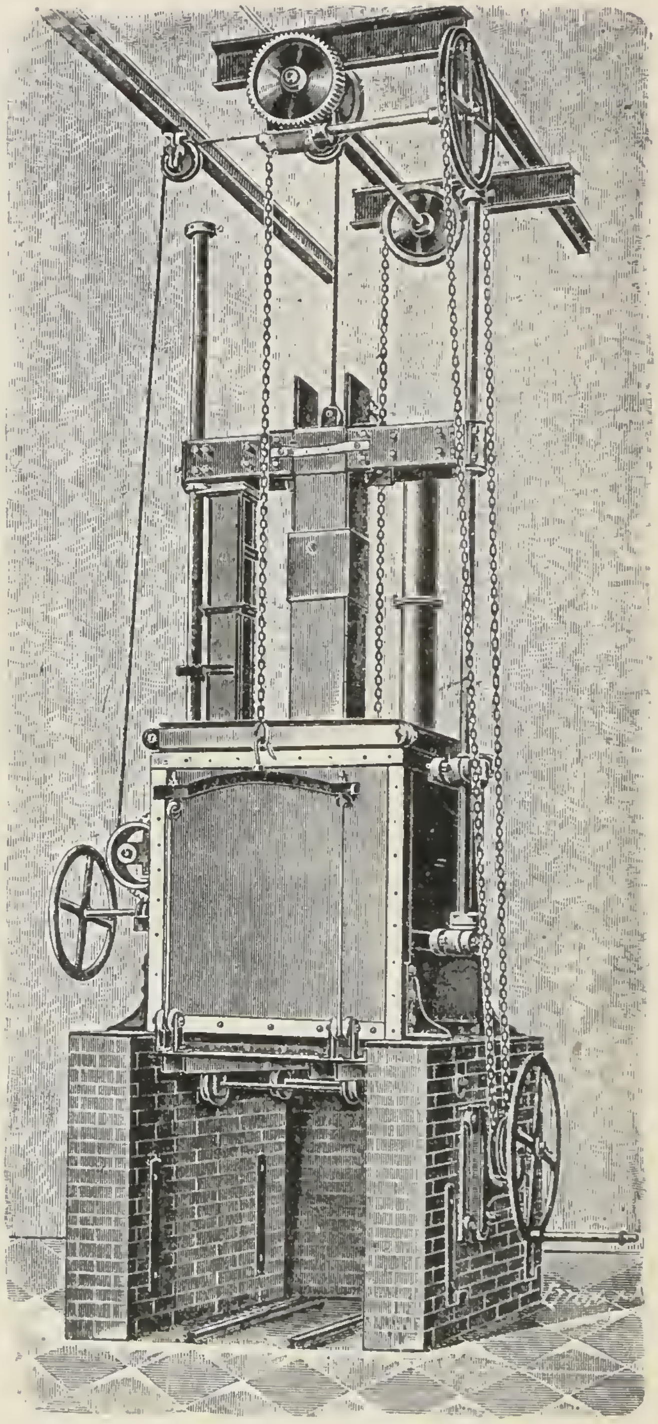

FIG. 1.—VIEW OF ELECTRIC FURNACE, MADE BY DEUTSCHE GOLD UND SILBER SCHEIDE ANSTALT.

From that moment the industry began to develop with gigantic strides, too fast indeed, for in 1900 many of the weaker works had to shut down, owing to over-production.

Carbide of calcium consists simply of 62·5 per cent. by weight of calcium, and 37·5 per cent. of carbon, and is formed by fusing together, in the electric furnace, a mixture of lime and coke, charcoal, or anthracite coal. Its specific gravity is 2·22. Theoretically, it should yield, on being brought into contact with water in proper proportions, 5·9 cubic feet of acetylene at a temperature of 60° F. Owing, however, to various causes, the yield is rarely more than 4·8 cubic feet per lb. of carbide. In appearance, it much resembles some kinds of limestone; but varies in colour from almost black to a lightish purple. It is almost as insensible as stone to fire, or anything except water, brought into contact with which it will produce a volume of acetylene equal roughly to 400 times the space occupied by the carbide when broken ready for use.

Carbide is sent out by the factories broken to almost as many sizes as there are factories. The sizes most used in the United Kingdom are 6 in., 4 in., 2½ in., 1 in., ¾ in., and ⅛ in. mesh. The 2½ in., owing to the dimensions of trays or cells generally used, is the size most suitable for the majority of generators; the ¾ in. is the best size for cycle lamps.

Although experience is growing, many generator makers, and still more private users, do not yet realize the importance of obtaining carbide of a proper size for the kind of generator they sell or use. Small pieces should not be used for generators working on the "drip system," or where the water rises to, or falls upon, the carbide in small quantities; nor should very large lumps be used where the carbide is allowed to fall into an excess of water.

No high-class carbide works now send out carbide that has not been properly screened, but many carbides, even of good quality, are so soft, owing to the method of manufacture, that attrition during transport will cause a considerable quantity of dust, the bane of all generators, to be formed. As a rule, carbide made on the "tapping" system, *i.e.*, carbide drawn off in the molten condition through a tap-hole in the furnace, bears transport better than any other, as it is harder and more compact. It is a singular fact that even when a "tapping" furnace is used, all parts of the same charge will not yield the same amount of gas per lb., so that the only way to obtain an approximately equal yield per drum is to break up an entire charge, carefully sample the various parts, and fill each drum with pieces from various parts.

We give here an illustration of one of the most successful electric furnaces for the manufacture of carbide of calcium. The first is that designed by the German Gold and Silver Refinery, of Francfort, which has been supplied to a great number of works in Europe.

The mixture of lime and coke, or coal, is not broken into dust, but into pieces about the size of a nut, and fed into the furnace.

The products of combustion, which rapidly eat away the electrodes, are led away at the side of the furnace, and the cost for electrodes thereby greatly reduced. This furnace is a so-called "ingot" furnace, *i.e.*, the carbide is not "tapped" off, but is allowed to remain in the furnace and cool, when it is removed in the solid state. It gives a remarkably high yield per unit of electric energy employed, the guarantee being 5 kilos (say 11 lbs.) of 4·8 ft. carbide per kilowatt-day. In actual practice this figure is usually exceeded.

The next furnace we illustrate shows another system, *i.e.*, the "tapping" one referred to above. This method of making carbide is gradually displacing the "ingot" system, owing to the carbide produced by it being more regular in quality, and more homogeneous.

In the "ingot" furnaces only the centre part, or "core," consists of good quality carbide; the outer part is "crust" or "shell," giving too little gas to be sent out, and as it is, as a rule, extremely difficult to distinguish where "core" ends and "shell" begins, and workmen cannot always be depended on, "ingot" carbide often proves to be a source of much trouble to the maker. "Tapped" carbide can, on the other hand, be always relied upon to give satisfaction if good materials be used and reasonable care be exercised.

The "tapping" furnace we illustrate is that made by the Keller and Leleux Co., of Paris, which many of our readers probably saw at the late International Exhibition. The drawing shows how the molten carbide is drawn off from the furnace. To get over the difficulty of the tapping-hole clogging, a difficulty which causes much anxiety in carbide works, Messrs. Keller and Leleux allow the hole to gradually close up, and a cake of carbide to form in the furnace. The power is then transferred to a second furnace, and the first one allowed to cool down, when the carbide remaining in the tapping-hole and furnace can easily be removed. Lately this firm have devised an improved furnace, to a great extent obviating the difficulty of the tapping-hole choking up.

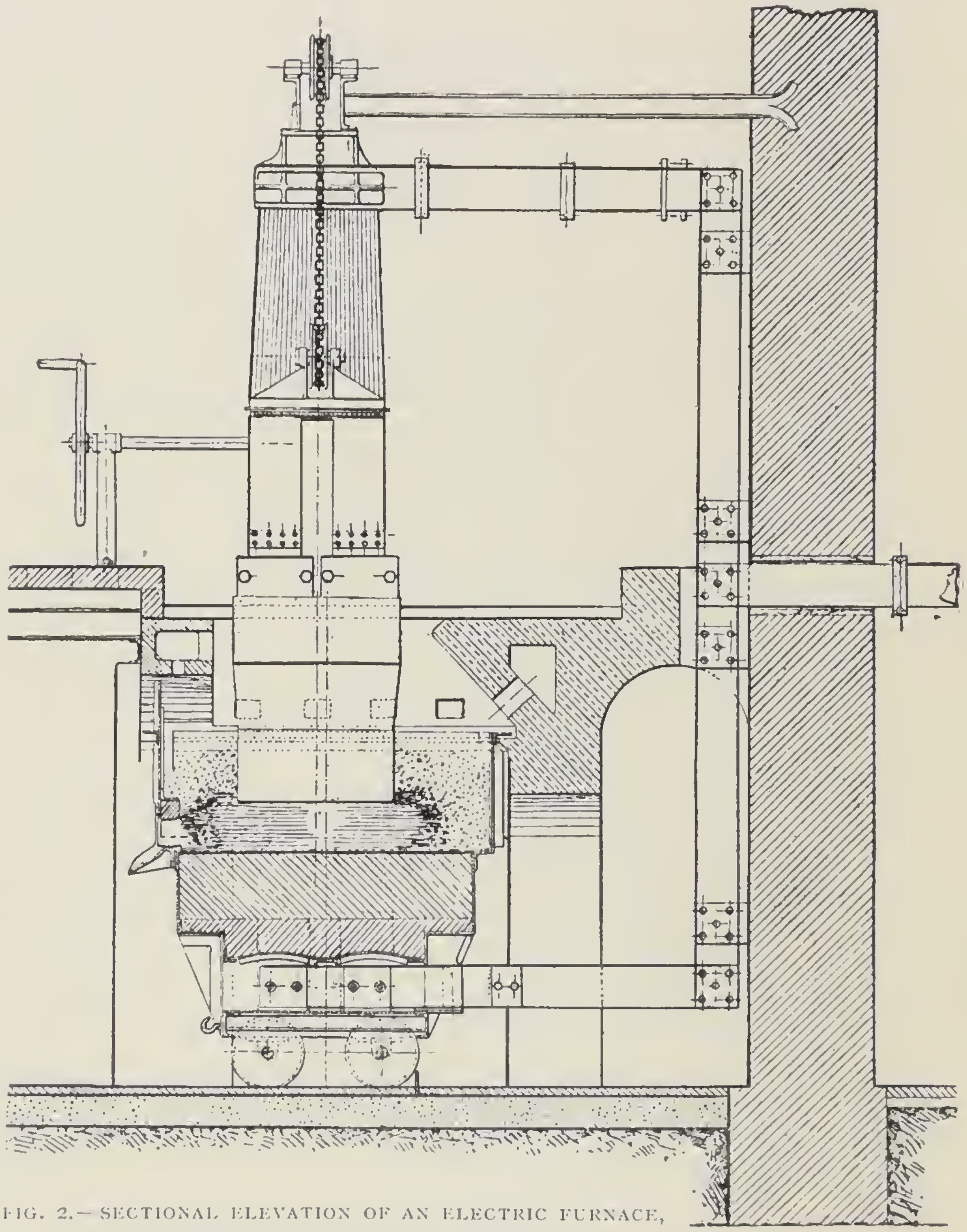
FIG. 2.—SECTIONAL ELEVATION OF AN ELECTRIC FURNACE, MADE BY MESSRS. KELLER AND LELEUX.

This furnace is one of the best of its type, and in actual working gives approximately the same results per kilowatt of energy as the ingot furnace of the Francfort firm. The Francfort furnace has been the most extensively used by works adopting the "ingot" process, while the same may be said of the Keller and Leleux furnace for the "tapping" process.

In electric furnaces, a distinction is not only made between "ingot" and "tapping" types, but the furnaces are further sub-divided into "arc" and "incandescence" groups. In the case of the latter

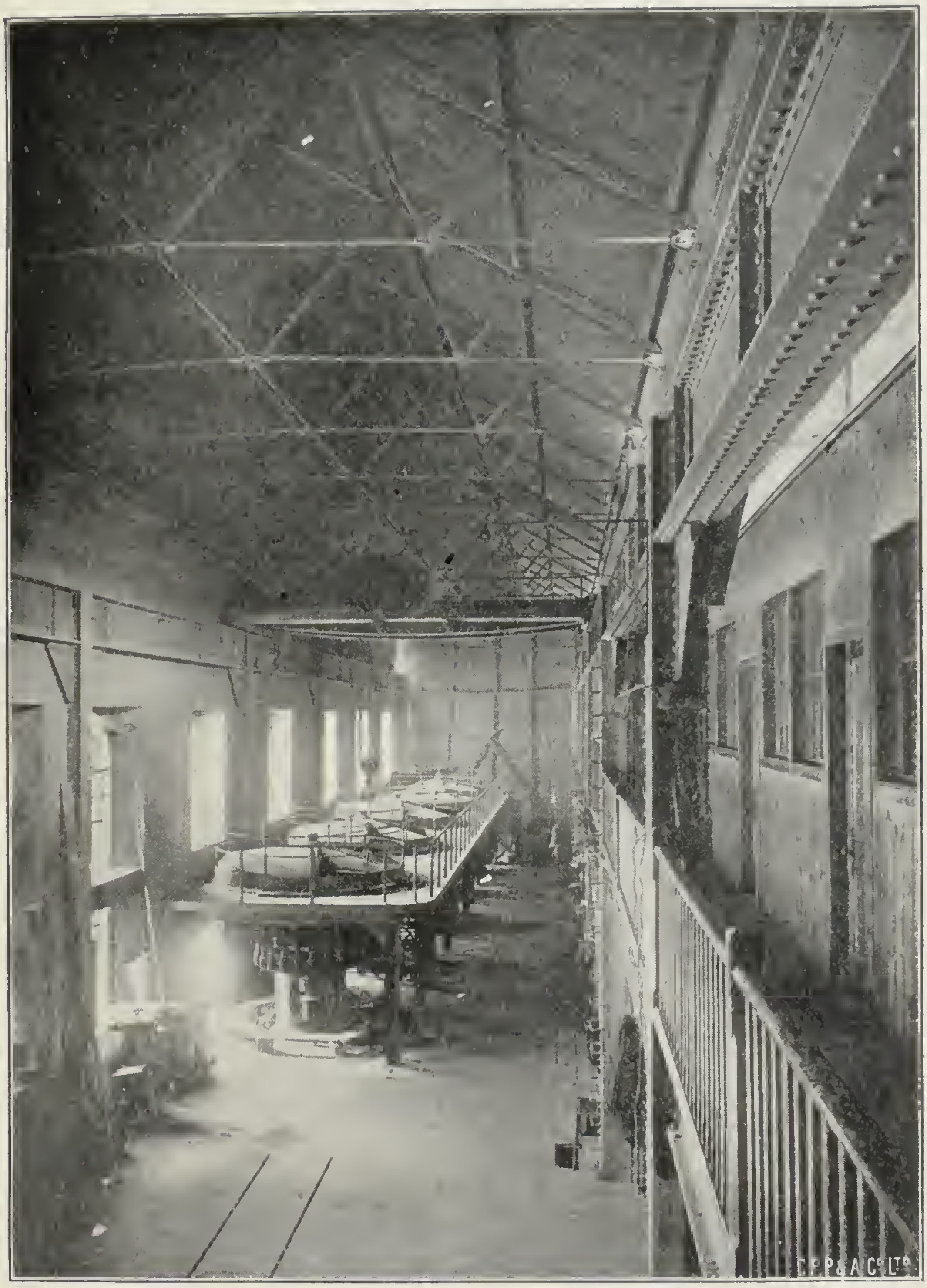

FIG. 3.—DYNAMO ROOM AT FOYERS CARBIDE FACTORY.

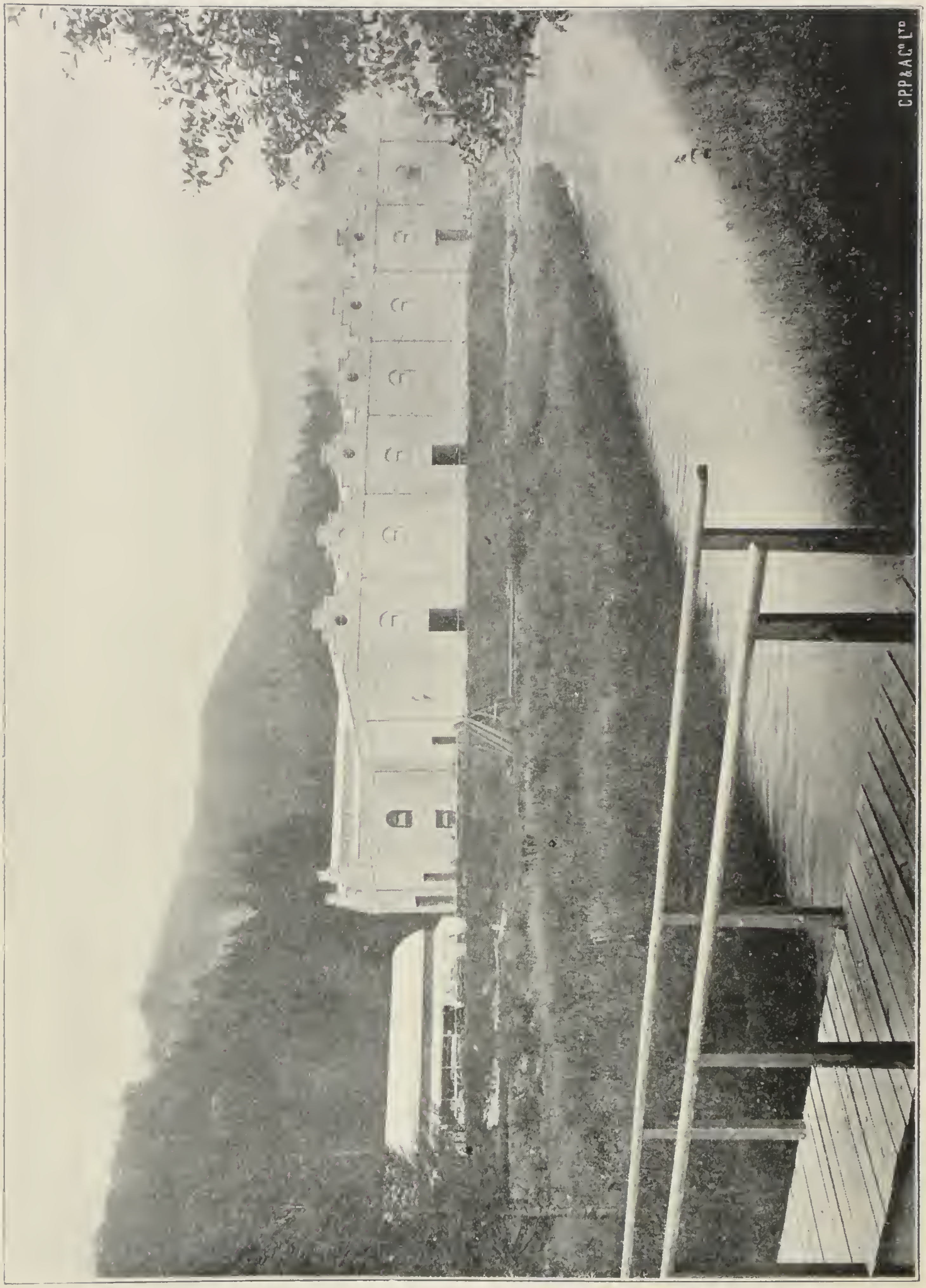

FIG. 4.—THE CARBIDE FACTORY OF THE ACETYLENE ILLUMINATING CO. AT FOYERS.

the electric arc proper is not used, the resistance of a poor conductor, such as a carbon rod, broken pieces of carbon, etc., being employed to produce the electro-thermic effect required.

In spite of the fact that the two Cowles, the fathers of the electro-metallurgical production of aluminium, used incandescent furnaces, and these have also been successfully employed for other purposes, such as the production of carborundum, a really successful carbide furnace on this principle was not devised until the Giffre Electro-Chemical Co. were able last year to get over the difficulty of making the incandescent furnace a "tapping" furnace, and thus obtaining carbide of equal homogeneous quality. The Giffre furnace has been steadily improved, and the yield is so good, both as regards quantity and quality, that the designers anticipate obtaining in the near future much better results than shown by any arc furnace. The consumption of electrodes, a very sore point with carbide makers, is extremely low with this furnace.

In the meantime, the above-mentioned firm (Keller and Leleux) have also introduced a most ingenious tapping furnace working on the incandescence principle. Space, unfortunately, prevents a full description being given, but we may mention that the furnace consists practically of a crucible with two vertical electrodes arranged in it side by side, one being movable in two directions, viz., vertically and horizontally, in such manner that at the moment of tapping, it is close to the side of the crucible where the tapping hole is situated, and thus keeps the carbide near the tapping-hole in a perfectly molten condition.

With care in the manufacture, a high-grade carbide can be made from any good metallurgical coke, charcoal, and most of the anthracite coals from the South-west Wales anthracite field. This latter district is now supplying the bulk of the carbon requirements of the European carbide works.

The good metallurgical cokes contain, as a rule, very little phosphorus, while the Welsh anthracites, usually used for carbide making, often show either the merest traces, or practically none at all. All, on the other hand, contain a fair proportion of iron and sulphur, originating, as a rule, from iron pyrites. Nearly all the sulphur is evaporated off in the electric furnace; most of the iron remains, and part of it forms the bright white metallic specks visible in most carbides. The bulk, however, is, as a rule, melted down into a solid lump of silicide of iron, when it can usually be detected and picked out. Occasionally it escapes attention, and is found by the generator user in the residue. Really good lime, on the other hand, is not easy to obtain. The greatest enemy in the way of impurities is magnesia, which appears to coat the lime and carbon with an extremely fine film, preventing, to a great extent, proper chemical union, so that a charge of what appears to be perfectly fused carbide will sometimes yield so little gas that it cannot be sent out.

The next worst enemy is phosphorus, found in many limes in the shape of phosphate of lime. It is to this impurity that is due what is known as acetylene "haze," *i.e.*, a vapour-like cloud, which, in the case of very bad carbides, used without proper purification of the gas, can be so dense that it is difficult, as the writer once saw, to distinguish the performers on the platform across a large concert room.

Silica is generally held to be very prejudicial, but the writer believes that a much higher percentage of this oxide can be tolerated in the raw materials than is generally believed to be the case. One of the best carbides made in the South of France is prepared from anthracite small coal, "duff," which has been shown by regular analysis of each consignment to contain, on an average, 10 to 11 per cent. of ash, fully one-half of which is stated to be silica.

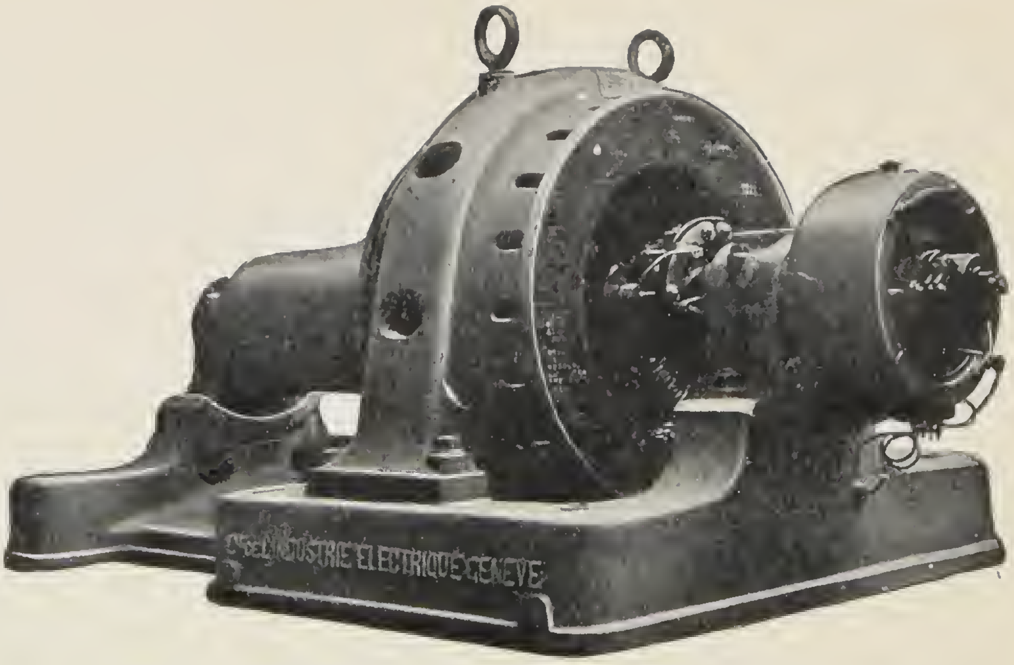

FIG. 5.—SPECIALLY DESIGNED ALTERNATOR, BY ELECTRIC INDUSTRY CO., GENEVA.

Although anthracite is now employed to so great an extent, metallurgical coke is generally preferred by carbide makers, where it can be obtained at approximately equal prices, the carbide produced from coke being of slightly better quality.

Gas coke is generally thought to be unsuitable for carbide making, but it is worth mentioning that the extensive carbide works at Deutsch-Matrei, Tyrol, have been using it.

It is often stated by laboratory carbide experts that a greater proportion of lime is required to make "tapped" carbide than to make "ingot." Such is, in the writer's experience, not the case. On the contrary, both the works which claim to hold the record for low consumption of lime per ton of carbide made, use the tapping process. It would also appear from the figures which have been published from time to time—and especially from the paper warfare that took place in Germany between Birgson and Frœhlich in 1900—that "tapped" carbide can be produced at least as economically, even as regards the quantity of current used, as "ingot" carbide of an equally high standard of quality, say 4·8 cubic feet per lb. Nor have any facts of practical value been adduced to show that the statement made by Lewes, probably on the information he received from Germany, to the effect that a higher temperature is required in the furnace to tap the carbide, is correct. Dr. Frœhlich, who has probably had more experience than Prof. Lewes, says the exact contrary is the case.

The heat required to fuse lime and carbon together in order to make carbide is generally given at 3,000° C. This figure is probably exaggerated. The writer has assisted at commercial runs when a higher yield of c.c. has been obtained per unit of current used than the theoretical maximum yield amounts to, basing on above temperature, and allowing for

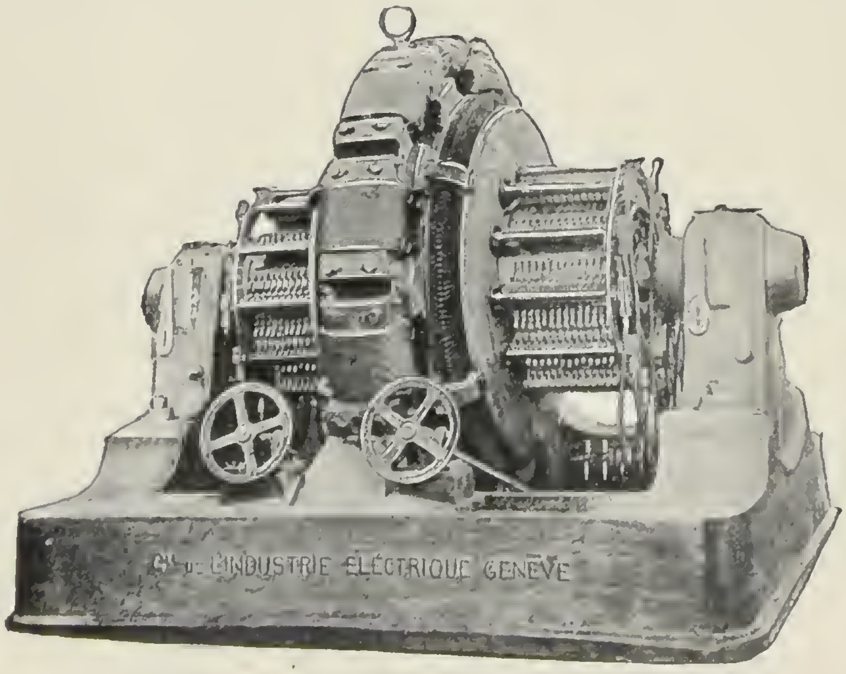

FIG. 6.—SPECIALLY DESIGNED CONTINUOUS CURRENT DYNAMO.

the difference between the quality of the commercial carbide produced and theoretically pure carbide. The Alby carbide works claim to produce more carbide per h.-p. year than the theoretical yield basing on a temperature of 3,000° C.

At the present time, a first-rate furnace will produce about 13 lbs. of c. carbide of 84 per cent. purity per kilowatt-day of 24 hours (the current measured at the furnace connections), equal to about 1·3 ton per h.-p. and year of 300 days. Owing to breakdowns, occasional failure of charges, etc., one ton of 84 per cent. carbide per h.-p. year is at present looked upon as a fairly good output.

COST OF PRODUCTION.

Many of the laboratory experts put the cost of making carbide at £2 10*s.* to £3 10*s.* per ton above the cost of the power; thus, with power at £2 per ton, the total cost would be £4 10*s.* to £5 10*s.* per ton. Adding, say, £2 per ton for costs for management, this makes the cost, exclusive of power, £4 10*s.* to £5 10*s.*

The fallacy of this calculation is clearly shown by the fact that when the price of carbide dropped, towards the end of 1900, to £12 per ton at the factory, including drums, the cost of which can be taken at £2 5*s.* per ton, half the carbide factories in Europe had to shut down. One of these, which had been working at full power, paid only 30*s.* per electric h.-p. year of 7,200 hours, the power being measured by a meter installed in the works, at a few yards' distance from the furnaces.

The writer has had the opportunity of comparing figures with many prominent makers, and the general opinion seems to be that, without allowing for any profit, and with power at £2 per electric h.-p., and year of 7,200 hours, a price of about £8 to £9 should be the cost of production, when working on a large scale. To this price must be added the manufacturer's profit and the cost of drums, so that the statement of the German experts that £13 to £14 is a fair selling price at the works, including drums, seems not unreasonable. Without doubt, however, this price will go down: on the one hand, owing to constant improvements in the manuture; and on the other, owing to the recent great drop in the price of the carbon—coke or coal—used.

STORAGE OF CARBIDE.

The Board of Trade being of opinion that the stone-like solid carbide "presents dangers similar to those presented" by the fluid petroleum, has placed the former, with a few alterations and additions, under the provisions of the Petroleum Act of 1871.

Five pounds of carbide may be stored without a licence, provided that it is kept in hermetically sealed metal receptacles, holding not more than 1 lb. each. The ordinary, self-closing 1 lb. tins are usually held to comply with these conditions. On the Continent, as a rule, 10 kilos (22 lb.) may be stored in one vessel without a licence, and the limit will probably soon be raised in the United Kingdom.

Where more than 5 lbs. are stored, a licence, costing 5*s.*, must be obtained from the "local authorities."

These are:—

(*a*) In any harbour: the Harbour Authority.

(*b*) In the City of London: the Corporation.

(*c*) In Greater London: the London County Council.

(*d*) In any borough: the Town Council.

(*e*) In any place in Ireland within the jurisdiction of any Trustees or Improvement Commissioners: the said Trustees or Commissioners.

(*f*) In any place in Scotland within the jurisdiction of Police Commissioners or Trustees exercising the function of Police Commissioners : the said Commissioners or Trustees.

(*g*) In places where there is no local authority as defined above :

(1) In England and Wales : the District Council.

(2) In Ireland : the Justices in Petty Sessions.

(3) In Scotland : the County Justices. The licences are for one year, and renewal must be applied for if desired.

Little difficulty is usually encountered in obtaining licences. For quantities up to 1 cwt. a dry cellar, room, or shed is usually passed. Above 1 cwt., the carbide must usually be stored in a shed or outhouse not connected with the building (although a shed built on the flat roof of a house has been passed).

All vessels containing carbide must be labelled :

"CARBIDE OF CALCIUM.

"DANGEROUS IF NOT KEPT DRY.

"The contents of this package are liable, if brought into contact with moisture, to give off a highly inflammable gas."

They must also bear the name and address of the owner (in the case of a vessel kept) ; or the sender (in the case of a vessel sent or conveyed) ; or of the vendor (in the case of a vessel sold or exposed for sale).

The maximum weight allowed to be packed in each drum varies, but is usually 1 to 1¼ cwt.

CARRIAGE OF CARBIDE.

The British railways require the carbide to be packed in substantial, hermetically sealed iron drums, or, if in tins, the latter must be packed in iron drums, or stout cases, iron bound. Each package must be labelled in the same manner as the vessels, and a special consignment note must be used.

As carbide is, in many cases, only carried on "explosives" days, great delays are often experienced, especially when the consignment has to pass over two or three systems.

British shipowners have steadfastly set their faces against carrying carbide, although it is an undoubted fact that it is infinitely safer than a vast number of other articles carried. Unwillingness to investigate a new branch has practically driven this large and increasing trade into the hands of foreign lines ; the export of carbide from British ports is at present impracticable.

ELECTRIC PLANT.

As a rule, the current used for carbide making is alternating monophase, although in some instance triphase is employed, notably in the case of the works at San Marcello, North Italy.

Preference has been given, in the majority of cases, to the alternating type, owing to its ability to withstand the very exacting requirements of carbide manufacture.

Herein are shown, in Figs. 3 and 4, two dynamos especially designed for electrothermic purposes by the Electric Industry Co. of Geneva, who have supplied the greater part of the dynamos employed for this work in Europe.

While it is undoubtedly a fact that for the manufacture of calcium carbide alternating current is to be preferred to a continuous current, the writer would certainly not, at the present moment, advise its adoption, as without costly rotary transformers it is difficult to utilize the current for any other purpose if, as at the present moment, the output of carbide exceeds the demand. If direct current be used, the prime cost of the plant is somewhat increased, but the current becomes available for making alkalies, extracting and depositing copper, and various other electrolytic, as well as electrothermic, purposes.

For the foregoing information I am largely indebted to Mr. Bingham, who leaves hardly anything to be said on the subject of any service to either the generator maker or user, except, perhaps, to emphasize the fact that carbide varies both in quality and in its action in the generator, and to obtain the best results this point should have more attention paid to it than has been the case hitherto.

For large machines of the "drip" or "*slow* contact" type the largest lumps procurable are the best, and yet, up to the present, there has been the greatest difficulty in making certain of supplies of the 4 to 6 in. sizes, which are required by at least two of the foremost generators on the market, and would be used by many others if proper attention were given this point by the makers of the apparatus. This is not the fault of the carbide makers so much as that of the users.

It is rather a pity that the "ingot" carbide, formerly made at Foyers, should be now almost unprocurable. The large lumps or "**H**" size of this make could not be beaten for "drip" or "slow contact" machines, probably owing as much to the shape of the lumps as to the make. The large pieces of the "tapped" carbide have very irregular surfaces, and are more or less of a flat shape, while those of the "ingot" make were larger, of straighter surface, and more nearly of a square shape. Irregularity of surface and a flat underside doubtless increase the tendency to intense local action.

The ideal form of carbide for this type of apparatus would doubtless be that of comparatively thin plates or rods standing upright, and separated from each other by a space equal to that occupied by the excess in bulk of the moist lime produced by the action. It is practically impossible to satisfactorily generate acetylene from a mass of comparatively small lumps of carbide.

The question of quality is practically one of economy only. A poor make of carbide is not necessarily impure in the sense of containing objectionable products, and may be caused by an excess of either lime or carbon, by incomplete combination in the furnace, or by a mixture of "crust" with the good. Such carbide, if sold at an equivalent price, is as good for most generators as one giving the full yield of gas; and even a carbide containing an excessive amount of sulphur and phosphorus can be utilized to produce pure gas at a slightly increased cost for purifying material.

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CHAPTER II.

PROPERTIES OF ACETYLENE.

ACETYLENE, so named from its relationship to the radicle acetyle, and known during its earlier history as klumene, was first described in 1836 by Edmund Davy as a gas obtained by treating with water a residue frequently found in the production of potassium from cream of tartar and charcoal, and was called by him bicarburet of hydrogen.

It was not, however, until after 1892 that this gas was used outside the laboratory, its commercial production having been inaugurated by the enterprise of Willson, who appears to have been the first to produce calcium carbide in large quantities; and about 1895 the industry was introduced into Great Britain by the Acetylene Illuminating Co. starting the manufacture of carbide on a commercial scale.

Very little was known of acetylene until the researches of Berthelot in 1859, which made clear its true composition and method of formation. From this time our knowledge has steadily increased until it has become probably the best known of the hydro-carbon gases.

Pure acetylene is a gas of a faint ethereal odour, but as usually prepared it has a strong smell, due to a small proportion of phosphorous and sulphur compounds, which in the very slight traces present in the gas after the ordinary purification are sufficiently pungent to insure the immediate detection of any leakage.

For facility in reference, the figures relating to the composition and properties of acetylene are given in tabular form :—

Percentage composition by weight	Carbon 92·3 per cent Hydrogen 7·7 ,,
Formula	C_2, H_2.
Molecular weight	26.
Density	13.
Specific gravity, calculated	·898.
Specific gravity, found	·9 to ·92.

1 litre at 0° C. and 760 mm. = 1·165 grammes.

Heat of formation	47,700 calories.
Specific heat	1·26.
Heat of combustion	321,000 calories.
Temperature of combustion, calculated	11,180° C.
Freezing point	– 82° C.
Critical point	37° C.
Vapour tension at critical point	68 atmospheres.
Vapour tension at 0° C.	21·53 ,,

1 volume liquid = 400 vols. gas.

Acetylene is soluble in water to the extent of a little more than one volume, but in the ordinary generating apparatus this is found to give but little trouble, and unless the bulk of the water is agitated with the gas, this proportion is only reached after a considerable time. When testing for quantity it is advisable to use a saturated solution of common salt, which can take up only about 5 per cent. of gas.

In acetone acetylene is remarkably

soluble, one volume of this liquid at ordinary temperature and pressure taking up 25 volumes; and at a pressure of 12 atmospheres, 300 volumes of the gas. Other liquids in which its solubility has been the subject of experiment are given in the following table:—

AT ORDINARY TEMPERATURE AND PRESSURE.

1 volume of –		*Volumes.*
Water	dissolves	1
Carbon disulphide	,,	1
Petroleum	,,	1
Turpentine	,,	2
Amyl alcohol	,,	3·5
Stryolene	,,	3·5
Chloroform	,,	4
Benzine	,,	4
Acetic acid	,,	6
Alcohol	,,	6
Acetone	,,	25

Acetylene is endothermic; in other words, it splits up into its elements with evolution of heat. This takes place spontaneously at a temperature of 780° C., and has been shown by Prof. Lewes to be the probable cause of the intense luminosity of the flame. The sudden evolution of heat due to the splitting up of the acetylene molecules alone creates a sufficiently high temperature to raise the carbon to a state of incandescence, and when there is added to this the heat of the burning gas, the temperature is sufficient to account for the very high degree of luminosity to which the carbon is brought in the flame.

This property of acetylene might be looked upon with suspicion in a gas used for illuminating purposes, were it not that the decomposition takes place slowly and gradually only in the region affected by the heat, and is not propagated through the whole bulk of the gas, nor does it take place with any explosive violence unless the gas is at a pressure of about 30 lb. to the square inch.

At this pressure acetylene becomes an explosive, and for this reason its use in liquid or compressed form has been forbidden by the authorities.

The changes undergone during the slow decomposition of the gas when brought about by heating it to a temperature of 400° C. and above are extremely interesting, though probably not of much practical importance.

The first action seems to be the condensation of the gas into benzene and other polymers, which split up with formation of ethylene, a number of hydrocarbons, including methane, and a small proportion of naphthalene with a thick, viscid tar, and finally, at a red heat, carbon and hydrogen.

It is this decomposition that presents the sole difficulty to be found in the commercial production of acetylene, owing to the heat evolved by the reactions of carbide and water.

When diluted with some inert gas, acetylene will withstand a higher temperature than other hydro-carbon gases, and it may also be compressed with safety when diluted with a sufficient proportion of an exothermic gas.

Other properties of the gas when mixed with air, doubtless due to its endothermic character, are its low ignition point, the greater violence of the explosion, and the wide range of mixtures that are explosive.

The temperature of ignition being as low as 480° C., a mixture of acetylene and air may be exploded by a glowing cigar end or a heated soldering-bit. This has also caused some suspicion as to its safety in use, which might have some foundation if the leakage from burners or from defective fittings were likely to take place to the same extent as with coal-gas, or remain as long undiscovered.

The range of explosive mixtures of various gases and air are given in the following table, which shows the highest and lowest percentage of the gas capable of being ignited :—

EXPLOSIVE MIXTURES OF AIR AND GAS.

Acetylene	3 per cent.	to 82 per cent.
Hydrogen	5 ,,	72 ,,
Carbon monoxide ...	13 ,,	75 ,,
Ethylene	4 ,,	22 ,,
Methane	5 ,,	13 ,,

The minimum percentage given above for acetylene is considered by many experts as too low, and it is a fact that very weak mixtures are difficult to ignite, and the combustion is so feeble that they may in most circumstances be considered as comparatively harmless.

A peculiarity of acetylene is that in a confined space the most violent explosion is obtained, not with the mixture which is in the correct proportions for complete combustion, but with one containing 50 per cent. of the gas.

The only obvious explanation of this is to be found in the explosive properties of acetylene when under pressure. In burning a 50 per cent. mixture in a tall glass cylinder, open at the top, the flame will be seen to travel slowly downwards to the bottom of the vessel. Presuming the action in a confined space to be of the same character, the combustion once started may be considered as proceeding with increasing rapidity as the pressure due to the heated products becomes greater, until the unconsumed portion of the gas reaches a pressure sufficient to cause detonation.

Owing to the low ignition temperature of acetylene and air, wire gauze will not stop the propagation of the flame. A "Davy" lamp would be quite as dangerous as a naked flame in an atmosphere of this gas, and tubes or orifices that are used with a coal gas "Bunsen" burner would be many times too large for acetylene under the same conditions.

Le Chatelier gives the following table of diameters of tubes through which the flame would be propagated with various proportions of the gas :—

Percentages of Gas.	Flame Propagated in Tube of Diameter—
From 2·9 to 64	1·57 in.
,, 3·1 ,, 62	1·18 ,,
,, 3·5 ,, 55	·79 ,,
,, 4·0 ,, 40	·24
,, 4·5 ,, 25	·16 ,,
,, 5·0 ,, 15	·08 ,,
,, 7·7 ,, 10	·03 ,,

In a tube of ·02 in. the flame is not propagated with any mixture.

The combustion of acetylene gives rise to a very high temperature, which has been calculated for a mixture of air and gas containing 7·74 per cent. of the latter as 2,420° C., and with a mixture of oxygen and 50 per cent. gas, 4,000° C., or 1,000° C. higher than that of the oxyhydrogen flame.

The actual ascertained temperature of the acetylene "Bunsen" flame is still open to controversy, and has been given by various observers as low as 1,900° C.; but it is, in any case, considerably higher than that of the coal-gas "Bunsen," which is to be expected both from its composition and endothermic character.

Acetylene forms an interesting series of compounds with copper, silver, and mercury, the majority of which are explosive, and detonate from a blow or on heating. The name generally given to these compounds is that of acetylides, but their constitution is but little understood, and a number of apparently differing compounds are generally included in this term.

The only one at all likely to be met with in the use of the gas is that of copper. This compound appears to be formed very slowly and in small quantities where acetylene containing ammonia or the usual phosphorous and sulphur impurities is allowed to remain in contact with the metal, provided that the conditions are favourable. Pieces of copper and various alloys carefully insulated from one another were exposed to the action of impure gas containing ammonia for a period of nine months without showing any signs of the compound; but in another experiment where the metals were probably not insulated, and a much larger quantity of gas was brought into contact with them, two out of five strips were found with slight traces of acetylide.

When acetylene is brought into contact with a cuprous salt in a neutral or alkaline solution, copper acetylide is immediately formed as a reddish-brown precipitate, the exact composition of which is still uncertain, and is given by Berthelot as $2\ (C_2\,Cu_2\,H)O$; by Blochmann $C_2\,H_2\,Cu_2\,O$; and by Keiser $Cu_2\,C_2$. This precipitate is decomposed by hydrochloric acid with evolution of acetylene.

FIG. 7.—VIEW OF THE GIFFRE CARBIDE WORKS, WHICH SUPPLY A LARGE PORTION OF THE CARBIDE USED IN GREAT BRITAIN.

This reaction is one of the most delicate tests we have for acetylene, the merest trace giving in a solution of cuprous chloride containing ammonia the characteristic red precipitate.

An explosive compound is also formed from cupric salts, such as copper sulphate and nitrate, especially in the presence of metallic copper.

It is therefore very necessary in using copper salts for purifying purposes to make sure that the solution is acid, and remains acid while in use. In an acid solution the copper acetylide is not formed.

On storing acetylene for some time it was found to lose a portion of its illuminating value, and it has been also noticed that under the action of light a deposit was formed on the sides of the glass container. From whatever cause this action proceeds, it is not of any importance in the use of the gas for illuminating purposes, as the length of time required to bring about any appreciable change would never be allowed to lapse in ordinary cases between the making and use of the gas. A rest of a day or even two days would improve instead of lowering its value, by permitting of the solution or deposition of some of the impurities present.

Acetylene is not poisonous in the usual acceptation of the term. Air containing 20 per cent. can be breathed for a considerable time without ill effect, and until about 40 per cent. is present, no danger need be feared by a healthy person. Recovery from the effect of a poisonous quantity is much easier than with coal-gas, which is far more dangerous in much smaller proportion.

COMPRESSED AND LIQUID ACETYLENE.

Owing to the explosive character of the dissociation caused by local heating or the detonation of a fulminate in compressed acetylene, it is too dangerous for ordinary use, and, in view of the many possible causes of explosion, such as a hasty compression with insufficient cooling, or a sudden opening of a valve leading to the reducing valve or other small chamber, it should be handled with great care under all circumstances.

Shock does not appear to cause explosion; but a spark, the detonation of a small quantity of copper acetylide, or heating due to a sudden check in expansion, are all possible accidents even in the laboratory.

With a view to overcoming this objection, the gas has been dissolved in acetone, and in this condition, at pressures below 56 lb. to the square inch, is free from the dangers of compressed acetylene; but the gas resting above the liquid is not. At higher pressures than the above the liquid also becomes liable to explosion.

Apparently there has been found a reasonably successful way out of the difficulty, by using in place of the liquid acetone a mass of kieselguhr or other absorbent entirely filling the cylinder, and saturated with acetone, which is then used to absorb the compressed gas. With this material the explosion does not appear to be propagated beyond the region affected by the heat or other exciting cause, and as there is no necessity to leave any space unfilled by the saturated kieselguhr, there appears to be but little danger, provided that the cylinder is not subjected to the action of heat over a large portion of its surface, or long continued. It has been suggested that this cause of danger may be also eliminated by using a cylinder having seams or plugs of "fusible" metal, which would permit of the escape of the gas before any large portion of it were subjected to a temperature sufficient to cause dissociation.

Another method of compressing acetylene with safety is by mixing it with a good proportion of another gas, such as oil gas, which is being done by many of the Continental railways, and also by some of the English lines experimentally.

A mixture of 25 per cent. acetylene with coal or oil gas may be compressed to 200 lb. to the square inch, without exceeding the limits of safety.

SAFETY OF ACETYLENE AS AN ILLUMINATING GAS.

One of the objections to the use of acetylene as an illuminant that was frequently raised in the early stages of the industry, and is still, perhaps, the most vigorous of the prejudices against which it has to fight, is that of its alleged danger of explosion.

The only foundations for this suspicion are, firstly, accidents which have happened while using the gas, and, secondly, some of the properties due to its endothermic character.

Accidents which happen in the laboratory, and during experiments where the substance under examination is subjected to entirely unusual conditions, are to be expected with the most innocent of materials, and are not necessarily in the slightest degree an argument as to its danger. Leaving out all the accidents that come under the above heading, the remainder will be found due either to that old familiar source of accidents with coal-gas, viz., trying to find an escape with a light, or to some other circumstances that brought together acetylene, air, and a light, and which are more likely to lead to an accident with coal-gas than with acetylene, owing to the more powerful and unusual odour and the much smaller quantity in use in the case of the latter.

An explosion due solely to the faulty design of the generator is possible, but would display such an entire ignorance of the subject, or such a wanton and criminal neglect on the part of the manufacturer, that it is quite improbable. The only causes which one can imagine for an explosion of this kind would be—

(1) The existence of a pressure of gas capable of rupturing the container.

(2) The existence of a pressure of nearly 30 lb. to the square inch, together with a temperature of about 800° C.

(3) The presence of air in the carbide chamber, with a temperature sufficient to ignite the mixture of air and gas.

The only probable generator in which any of these conditions are at all likely to be found would be one in which there was no safety-valve or water-seal to the carbide chamber, and the outlet pipes were closed by cocks or liable to become choked up with a compact mass of lime or other substance, or one of the "dipping" or "displacement" type, in which the charge was uncovered, and a good proportion of air could be imprisoned in the same chamber.

The case against the gas itself, put in the strongest terms, is simply that—

(1) At a temperature of 800° C. it can split up into its elements with evolution of heat, and when under a pressure of about 30 lb. to the square inch with explosive violence.

(2) A mixture of acetylene and air in proper proportion will ignite at a temperature of 480° to 500° C., and therefore a lighted cigar may cause the ignition of an explosive mixture in the case of leakage.

(3) It is capable, under certain conditions, of forming with certain metals a compound that is explosive, and this may ignite a mixture of air and gas in some part of the generating apparatus.

Any idea of danger on the first count may be dismissed at once, seeing that at the highest pressures found in any generator the decomposition of the gas could only proceed slowly and harmlessly, as it is often found to do in a badly-designed apparatus that permits overheating. It would require a pressure of about one hundred times that ordinarily employed before the necessary conditions for an explosion could be obtained.

On the second count, which presupposes a considerable leakage of the gas, such as could only proceed from a broken or unplugged pipe, or from the generator itself, the danger would be so slightly increased by the low-ignition temperature that this cannot be considered as a valid objection.

Thirdly, although the compound formed by acetylene with copper is extremely explosive, the only damage one can conceive of as at all possible is that it might ignite a mixture of air and gas permitted to exist in some part of the apparatus. This compound is difficult to obtain even in the laboratory, and the conditions for its formation are never likely to exist in any acetylene apparatus even if made of copper, which metal would be far too costly for any generator maker to use. The quantity formed would, in any case, be too minute to become a source of danger by itself.

The fact that the explosion of acetylene is sharper than that of coal-gas in similar quantity, and that the proportion of gas to air required for explosion is less, does not affect the case, seeing that the force of the explosion is proportionate to the extent of the leakage, and that with acetylene not only are leaks far less likely to occur in the house, but they would also be, as a general rule, much less in volume, probably one-third to one-fifteenth of that of coal-gas, according to the nature of the leak.

The danger from explosion of acetylene inside the house is of the same character as that arising from the use of ordinary gas, but is less in degree for the following reasons—

(1) The more penetrating and unusual odour, and the higher specific gravity of acetylene, would both lead to an earlier discovery of a leak.

(2) The most frequent form of leakage, that from an unlit jet, would be but one-sixth to one-fifteenth the amount of a similar leak of coal-gas.

(3) The piping is of smaller size, is more carefully put up owing to the penetrating character of acetylene, and is, therefore, far less liable to develop leaks.

Whatever danger there may be in the generator shed is due primarily to a defect in the apparatus, and secondly, to the presence of a light at an improper time.

Once the generator is started and the air cleared out of it, a bonfire might be lit underneath without causing an explosion.

Danger from this source is only to be looked for in—

(1) Bad design.

(2) Leakage of gas.

(3) Smoking, or the use of a light while charging or repairing the apparatus.

(4) Accumulation of gas from partially used charges, or from residue confined in a closed pit or receptacle.

The design of the various types of apparatus is dealt with in another chapter.

Leakage owing to flimsy construction should condemn the apparatus. There is no difficulty in making a generator as sound and permanently strong in all its parts as an ordinary water tank. Leakage from an open cock, or carelessness in closing any part of the apparatus, would be culpable negligence on the part of the attendant, but can hardly be provided against, though any danger from this cause may be greatly minimised by having the generator shed freely ventilated both at top and bottom, or entirely obviated, as regards any serious consequences, by leaving the whole of one side open.

Smoking or using a light when charging or cleaning the apparatus should lead to nothing more than singed hair or skin.

Repairs, or testing for soundness, should of course only be performed by a person who thoroughly understands the nature of combustible gases. The only instructions necessary to give an ordinary gas-fitter who has no experience of acetylene apparatus, would be that the gas being soluble in water may be given off from any water left in the generator, and that a heated "bit" is quite capable of exploding a mixture of acetylene and air.

Partially used charges or residues should not be allowed to remain in any confined space. It is easy enough to find an open spot where lime may be thrown down, and if the residue is in the form of sludge an open-top barrel or pit can be used with perfect safety, or it may be run directly into the drains, if they are flushed down immediately after.

Taking into consideration everything that can be said against the use of acetylene, the only conclusion we can arrive at is that, used in the ordinary manner, it is not even as dangerous as ordinary coal-gas inside the house, and infinitely less dangerous than petroleum lamps. And in the generator shed, provided that the apparatus is properly designed and made, and the shed is partially open, so as to prevent any accumulation of gas through accident, there is no danger, except through gross carelessness while charging, repairing, or examining the apparatus with a light.

CHAPTER III.

PRODUCTION OF ACETYLENE.

WHEN calcium carbide and water are brought together, the reactions taking place may be symbolised by the following formulæ:—

$$H_2O + Ca\,C_2 = CaO + C_2H_2$$
$$CaO + H_2O = Ca\,(HO)_2\,;$$

or, combining the two:—

$$2\,H_2O + CaC_2 = Ca\,(HO)_2 + C_2H_2\,;$$

and where carbide is in excess and the temperature is high:—

$$Ca\,(HO)_2 + CaC_2 = 2\,CaO + C_2H_2.$$

The first molecules of water and carbide interact, forming quicklime and acetylene, the quicklime immediately taking up another molecule of water to form calcic-hydrate or slaked lime; when, provided that all the water has been used and there still remains some of the carbide, the calcic-hydrate is attacked by the carbide, forming two molecules of quicklime and one of acetylene.

So much heat is set free by these reactions that, unless carefully controlled, or dispersed immediately by the use of a large excess of water, it is possible for the temperature of the charge to rise above 800° C. in even small size generators, and probably 1,000° C. is often reached in some part of the charge with the worst offenders.

The reaction requires 36 parts of water to 64 of carbide, allowing half of the water for hydrating the lime; but in practice a larger quantity is necessary, to allow for evaporation and a portion soaked up by the residue.

The heat liberated by commercial carbide in an excess of water was found to be over 400 calories per gramme; in other words, from 1 lb. of carbide an equal amount of heat is set free to that given off by about 3½ pints of boiling water on cooling to ordinary temperature.

From these figures it will be seen that in generators treating the carbide with excess of water, nearly four pints would be required for every pound of carbide to keep the temperature below boiling point; and if the minimum quantity of water were used, nearly three-quarters of a pint would have to be evaporated to keep it from rising above 100° C.

But unfortunately for the manufacturer of acetylene apparatus, the matter is not so simple in practice. Owing to the residue forming a thick sludge or paste, the carbide quickly becomes surrounded and protected from the cooling effect of the water, and in spite of the large quantity of heat that water can absorb in forming steam, its *evaporation alone* cannot, under any circumstances, keep pace with the temperature. And, on the other hand, where it is endeavoured to control the production of heat by admitting the water very slowly, we are met by another difficulty. The conductivity of both the carbide and lime is too low for more than a very light duty, and in any spot where the water has penetrated too quickly, or where the bulk of material is too great, the rise in temperature is beyond the control of any poor conductor.

Another difficulty is to be found in the size of the lumps of carbide. When a piece weighing over half a pound is immersed in flowing water, traces of overheating will frequently be observed. The probable explanation is, that the heat liberated at the surface of the carbide is propagated partly inwards as well as out into the surrounding water, and the continual addition to this heat raises the temperature of the lump until it is capable of partially overcoming the cooling action of the water.

Dividing the charge into small portions is by itself a very imperfect palliative, as with an amount as small as half a pound the worst results of heating may be obtained.

Owing to the blind rush of inventors towards the ideal of an automatic feed that would make a storage holder unnecessary, and their infection of the manufacturer with the same craze, it has come to be regarded as almost a necessity that there should be some slight local overheating in all generators in which the water is fed to the carbide, and that if the overheating is but slight no great harm is done.

There could not have arisen a conviction more disastrous and more damaging to the interests of the industry. It has been almost the sole reason for the present lame and backward condition of the trade. Flimsy construction and complicated design are things that can be seen at a glance by the user and rectified in his next purchase or recommendations to his friends; but the troubles and worries caused by bad gas are apt to be looked upon by him as necessary accompaniments of acetylene lighting.

It cannot be stated or upheld in too forcible a manner that there is *no necessity whatever* for the slightest overheating of the charge in any type of generator, and that overheating *in any degree* will have a noticeable effect on the flames and burners in use.

TYPES OF ACETYLENE GENERATORS.

Generators fall naturally into two or more classes according to the way in which the dissipation of the heat, the most important point, is performed. The nearest approach to a true classification that recognised the fundamental differences was that of—(1) "water in excess"; (2) "carbide in excess"; which was satisfactory until it began to be disputed as to which class apparatus in which the water rose through the carbide belonged. This, however, did not show that the classification was inadequate, but that the generator was of improper design, seeing that for a satisfactory production of gas either the water or the carbide must be in excess at *every point* during the whole of the action, and that any gradual change from the one condition to the other inevitably leads to overheating.

If we take as one class all generators in which the heat of the reaction is taken up by the excess of water, and as another class those in which it is conducted away by the lime, unattacked carbide, and the moist gas, the two systems will never approach one another in any properly constructed apparatus.

Although, theoretically, if we take nearly equal quantities of water and carbide there should be a sufficient excess of the former to carry off the heat when transformed into steam, practically it is found that the action proceeds so quickly that the temperature rises far above boiling point before sufficient water can be evaporated, and in some part of the charge is almost certain to reach the polymerisation point of acetylene.

Perhaps a simpler mode of distinguishing the two classes would be by the terms "quick action" and "slow action," which could hardly be misunderstood, seeing that with the carbide in excess the action must take place infinitely slower than with water in excess if successful results are to be expected.

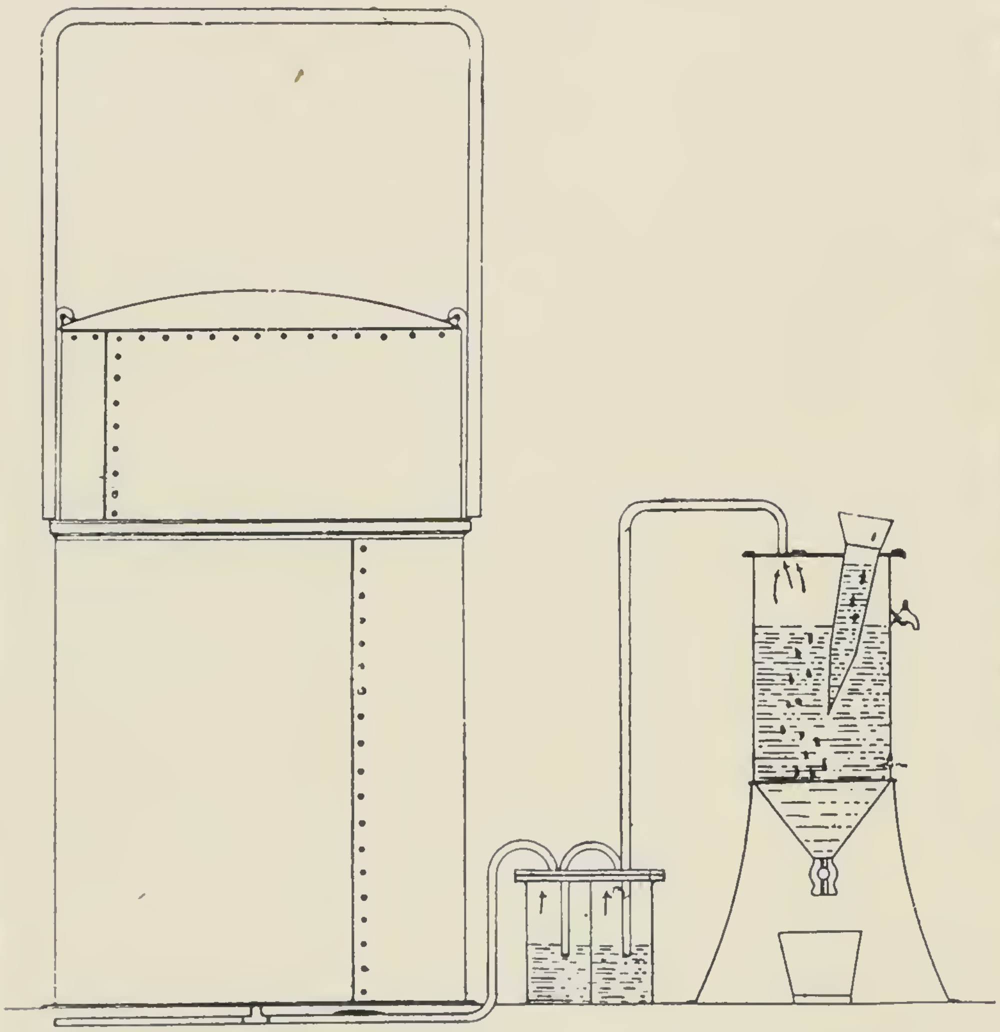


FIG. 8.—"PICTET" GENERATOR, IN WHICH THE CARBIDE IS ALLOWED TO FALL INTO THE WATER.

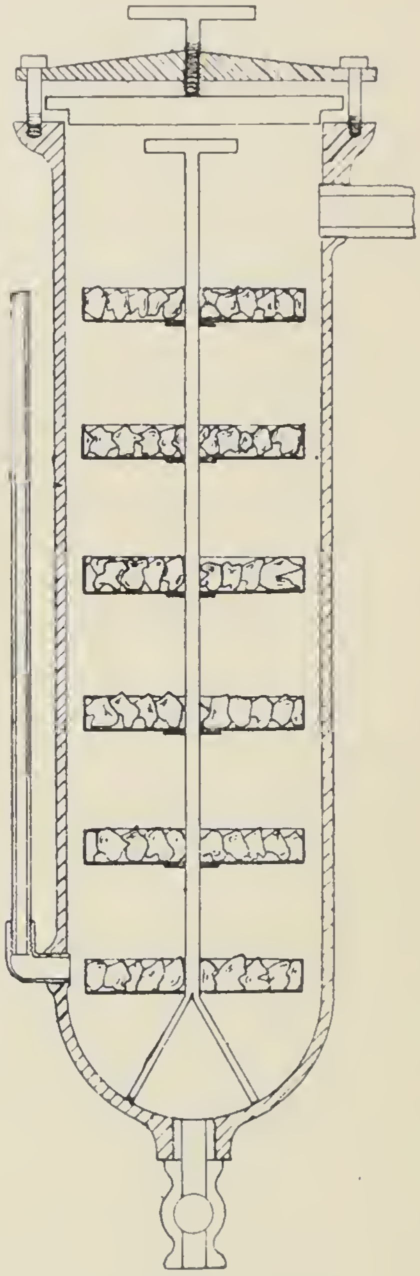


FIG. 9.—"WATER-TO-CARBIDE" GENERATOR, WITH WATER IN EXCESS.

These terms naturally provide a third, that of "controlled action," to distinguish a class of generator that has been lately coming into prominence, in which the energy of the reaction is controlled by the use of some third substance, such as oil or glucose.

These three classes are naturally to be found in many and varied forms, of which the only important types yet brought out may be placed under the headings of:—

"Quick Action" or "Water in Excess."

(1) Those in which the carbide is allowed to fall into the water (Fig. 8).

(2) Those in which the water in large excess rises over trays containing a small quantity of carbide and immediately floods them (Fig. 9).

"Slow Action" or "Carbide in Excess."

(1) Those in which water is dripped on to the carbide or on to the bottom of the tray of carbide, or rises up to it with extreme slowness (Figs. 10 and 11).

(2) Those in which a third, inactive, substance is used to bring the water slowly into contact with the carbide.

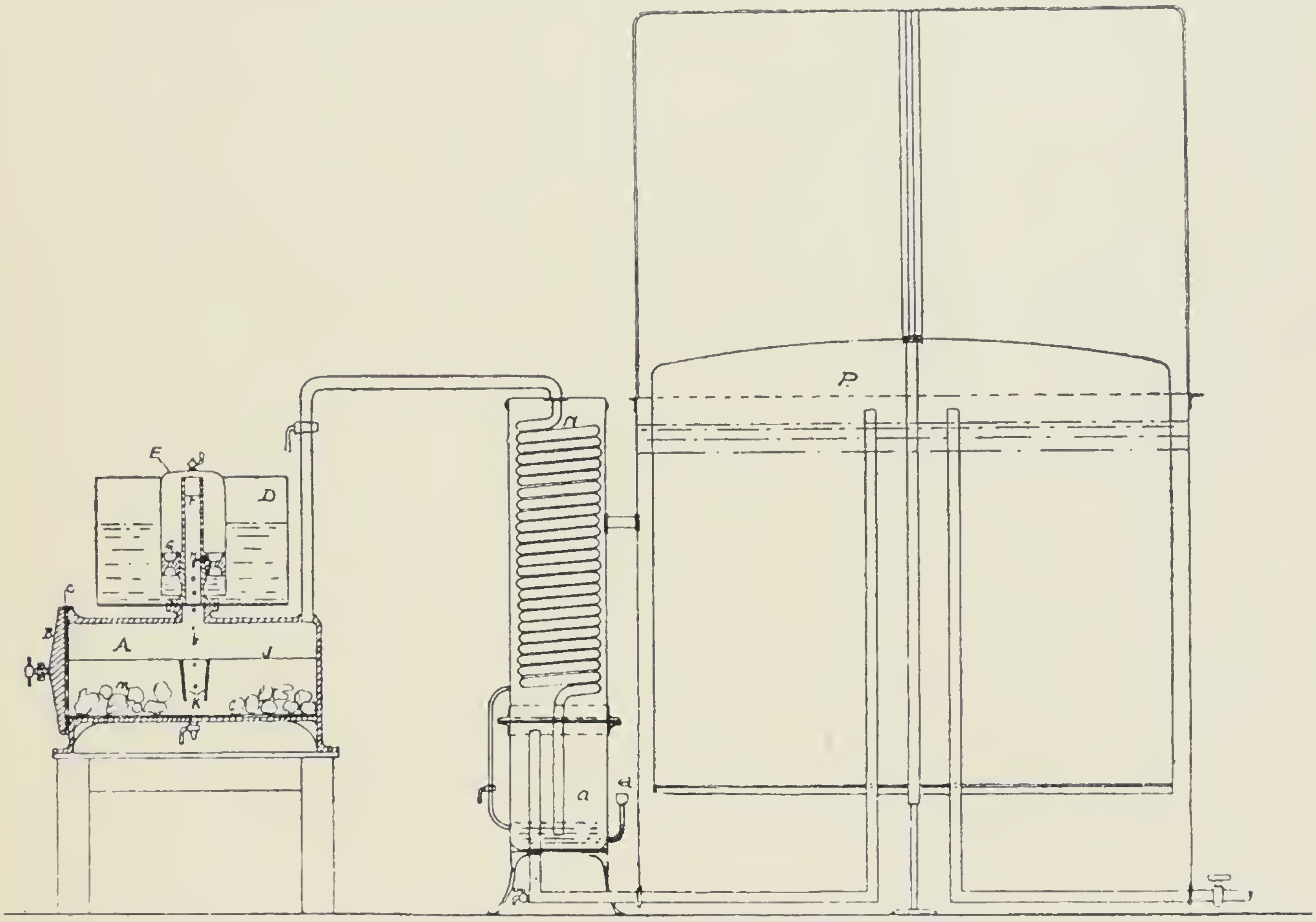


FIG. 10.—"FORBES'" GENERATOR, WITH CARBIDE IN EXCESS.

"Controlled Action."

(1) Those in which petroleum or other oil is used to retard the action (Fig. 12).

(2) Those in which glucose or other lime solvent is used, either with or without soaking the carbide in oil.

Of the "slow action" class our only examples at present appear to be some portable lamps and one large apparatus.

Many of the generators on the market are attempts to combine the two classes, for the sake of reducing the size of the apparatus or permitting the use of an automatic water supply with a very small storage of gas.

OVERHEATING.

In order to understand the causes of overheating, it is necessary to analyse the conditions existing in the charge where the carbide is surrounded by lime.

In the first place, where the lime is in the condition of a solid or only partially fluid paste. When we take into consideration the large amount of heat developed and the extreme quickness of the reaction, it is practically conclusive that between the surface of the carbide lumps and the wet lime there is a layer of practically dry lime through which the water reaches the carbide in the form of steam, and in this condition is unable to protect the acetylene, which at the moment of formation is therefore subjected to a very high temperature, and is not cooled down by the surrounding water till the damage has been done.

In the second place, where the lime is only slightly moist, but the mixture of lime and carbide is in too great a bulk; or in other words too large a surface of carbide is in action in a confined space, such as would be the case where the carbide was in comparatively small lumps and used in a layer of two or three lumps deep. Here, although the action might take place slowly, yet, owing to the large amount liberated and the poor conductivity of the materials, the heat could not be abstracted from the middle of the charge quickly enough to prevent a baking of the acetylene.

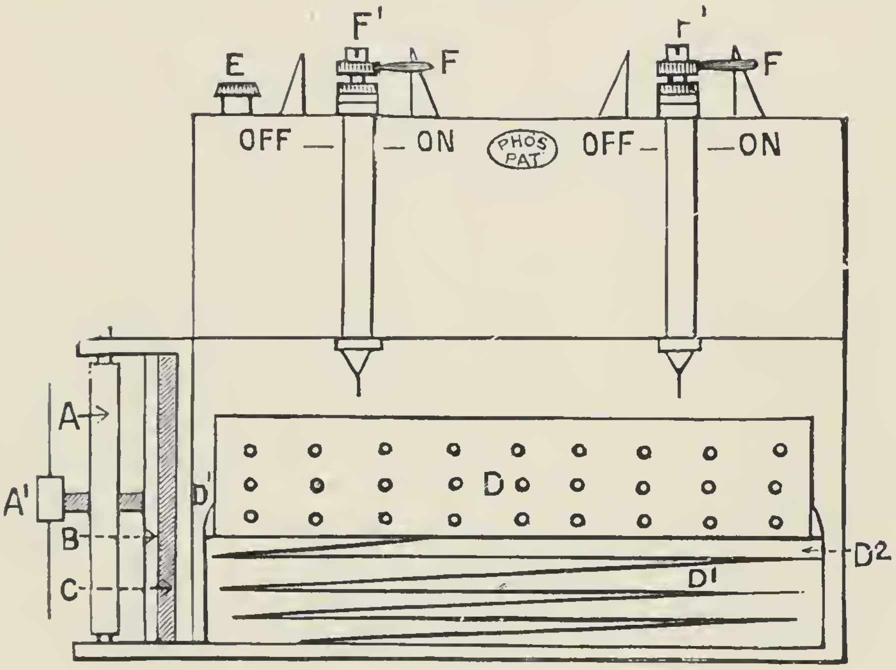


FIG. II.—SLOW ACTION "PHOS" LAMP GENERATOR.

To form some idea of the effect of attacking carbide by steam, a few ounces were placed on a grid in a metal tube through which a current of steam at 100° C. was passed. The result was an evil-smelling vapour quite unlike acetylene, and a thick deposit of tar.

There is probably a very similar action taking place in any case of overheating with carbide in excess. With water in excess tar may not be formed in any noticeable quantity, the destruction of the acetylene being checked at some little distance from each lump of carbide by the surrounding water. This, however, does not prevent polymerisation, which probably takes place at the moment the gas is formed.

The paramount importance of controlling the heat liberated when water and carbide are brought together in the generator is at once obvious when we consider the troubles caused by a high temperature, which are in the order of their importance—

(1) The formation of polymerisation products such as benzene, which cannot be entirely washed out of the gas, and causes endless trouble with the burners.

(2) The loss of gas, owing to its destruction or condensation into polymers.

(3) The loss of illuminating power, owing to the presence of gases due to the destruction of the acetylene, such as methane, ethylene, and hydrogen.

(4) The increase in the amount of impurities, such as ammonia, phosphorus, and sulphur, and the greater difficulty in removing them, owing to a change in the character of part of these compounds.

Of these the last is the only one that can be removed by after treatment.

The question naturally arises—What is the temperature above which it is unwise to allow the production of gas to proceed? The answer can only be 100° C., or the boiling point of water. Acknowledging that the gas will withstand a far higher temperature, yet once this limit is overstepped in any part of the charge, the heat has begun to show that it is beyond control of the water, and may in a few seconds rise to the decomposing point of acetylene.

In the types of apparatus in which the water is in excess, any increase of temperature over that of 100° C. would indicate that at the spot where this was measured the water was no longer in excess, and the heat, therefore, beyond this system of control. While in the types in which the carbide is in excess a temperature of anything over 100° C. would lead to the conclusion that in some part of the charge it was probably at or about to reach a much higher point, seeing that in this form of apparatus, owing to the bad conductivity of both the lime and the carbide, the temperature would vary in a space as small as one cubic inch.

In this latter class of apparatus the *average* temperature should not be much above 60° C., seeing that to prevent polymerisation it is imperative that there should be no chance of the heated carbide being acted upon by steam.

This may be considered a counsel of perfection, but if the gas is to be kept free from the most objectionable of its possible impurities perfection on this one point is of absolute necessity. It is not as though there were any engineering or other practical difficulties in the way. The attainment of this result is simply a matter of proportions, and not one requiring any skill in design.

The simplest way of considering the question is to bear in mind that wherever carbide is surrounded by wet lime overheating will take place, and consequently in the "quick action" type of apparatus it is necessary that the water should be in a state of constant agitation on all sides of each lump of carbide, and in the "slow action" type that the lime should be moist only, and should only attack a portion of the lump of carbide if of large size.

The most frequent causes of overheating found in the present designs are, where the water is in excess:—

(1) Insufficient water.

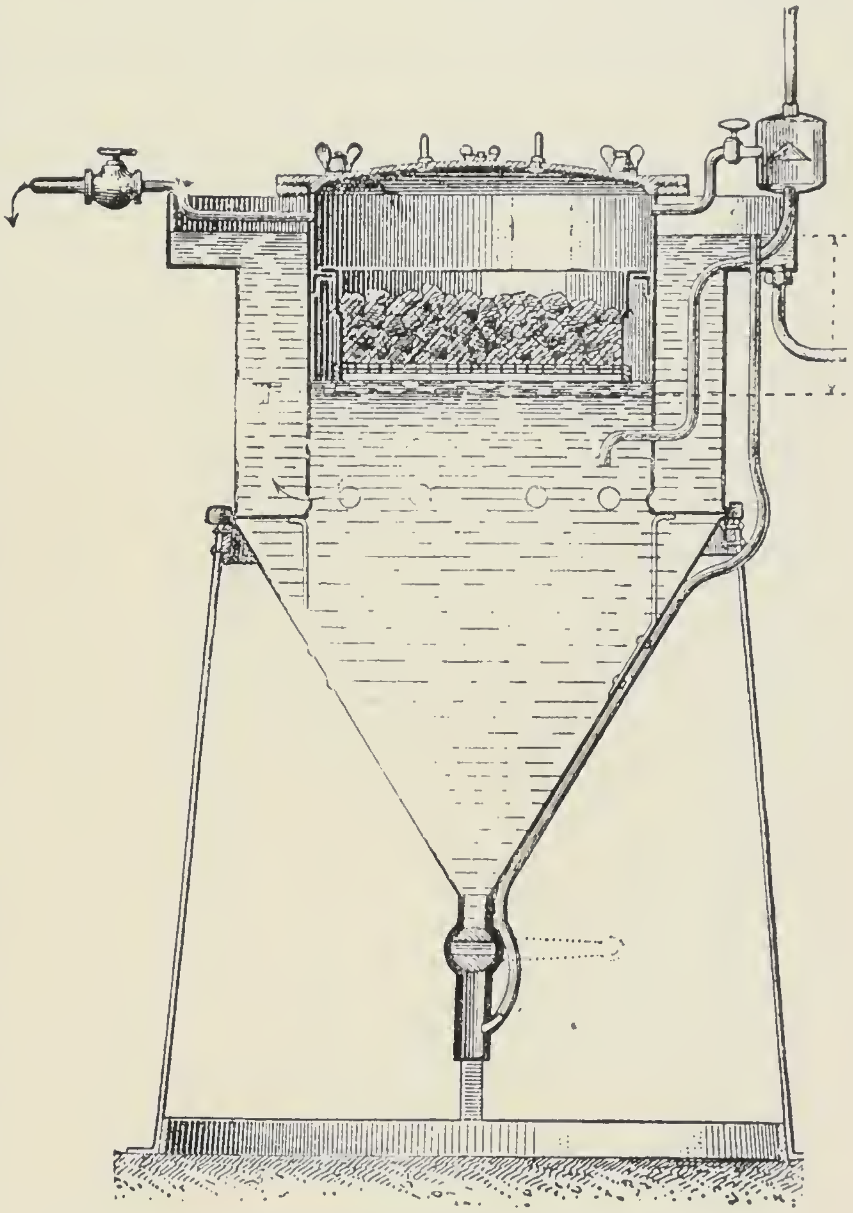


FIG. 12.—TURR'S GENERATOR, IN WHICH PETROLEUM OR OTHER OIL RETARDS ACTION.

(2) No provision for a circulation of water on all sides of the carbide.

(3) The use of large lumps of carbide ($2\frac{1}{2}$ in. and upwards).

And where the carbide is in excess:—

(1) Too quick a feed of water for the surface of carbide acted upon.

(2) Too deep a layer of carbide.

(3) The use of small carbide.

(4) Insufficient room to allow of the free expansion of the residue.

It cannot be argued that any skill or trouble is required to overcome any of these causes of high temperature, and yet it appears to be very often neglected, the explanation being undoubtedly that in order to obtain the greatest possible output from the smallest generator, the minimum space for the carbide and the quickest possible water feed are the objects aimed at.

The statement is frequently made that if there is any suspicion of overheating it is only necessary to reduce the output of the apparatus. This is obviously incorrect. Although in some designs it might slightly decrease the average temperature, in others it would only add to the trouble, and in any case would be powerless to overcome the imperfections of design.

With a properly designed apparatus the capacity of the "quick action" type is only to be measured by the diameter of the pipes leading to the holder, and with the "slow action" type by the size of the opening that admits water to the carbide; provided that correct principles have been followed.

The usual indications of overheating are to be found in—

(1) Carbonization of the burner tips.

(2) Comparatively low candle power of the flame.

(3) Brownish discoloration of the lime residue.

(4) Low yield of gas.

(5) High temperature of the carbide chamber or exit pipes.

With the exception of the discoloration of the residues and the heating of the carbide chamber, these may be the result of other defects in the installation; but heating should always be suspected till they are remedied.

The discoloration of the lime shows an advanced stage of overheating, as polymerisation products are formed before the tar. A pure residue is therefore not necessarily an indication that the temperature has been sufficiently low.

Where the carbide chamber is surrounded by water it is difficult to detect the appearance of heat, especially if the exit pipe is also concealed. Water-jacketing the carbide chamber has no other advantage, and is quite without effect in preventing or even minimising the evils of overheating.

PRINCIPLES OF ACETYLENE PRODUCTION.

Bearing in mind the troubles caused by overheating, it is obvious that the first point to consider, and the most important, is that of the control of the temperature of the charge, and until this has been thoroughly attained all other considerations are premature.

The difficulty exists not in the amount of heat liberated, but in the quickness of the action, and the bad conductivity of the materials. Therefore the only obvious methods open to us are either to spread the action over a large surface, or to apply directly to the point of heating some good conducting material.

One is apt to jump to the conclusion that in water, which is necessary to the reaction, we have the correct material correctly applied, and so long as it is in excess no more can be necessary; forgetting that water, unless rapidly moving, is a bad conductor of heat.

On examining the various types of apparatus in use, we find the following methods employed:—

(1) Projecting the carbide into a large body of water.

(2) Dividing the charge into small portions, and treating them separately with a comparatively small excess of water.

(3) Treating the carbide with successive small portions of water, which is in excess only during the first moments of the action.

(4) Applying the water slowly to a large surface of carbide.

(5) Attacking part of the charge only, and removing the lime from the surface of the carbide as quickly as formed, so that the water freely washes over the generating surface.

(6) Flooding the carbide with an excess of water.

(7) Bringing the water into contact with the carbide by means of a solid holding it in combination or by capillarity.

Of these methods the first is satisfactory, provided that the carbide is not in lumps larger than will pass a screen of 2 in. mesh, and that it is not allowed to fall into thick lime sludge, or to collect together in one spot.

The second is inefficient, and the third can only be described as bad.

The fourth is satisfactory, provided that the water is run in slow enough, and is not allowed to be even momentarily in excess at any spot.

The fifth requires the addition of some lime solvent, or a protective coating to the carbide not immersed in the water, with some means for removing or permitting the lime to fall away as formed. Efficiently carried out, it is very satisfactory.

The sixth is thoroughly good, provided that the size of the carbide is not above 2 in. mesh; that it is in small portions, so that the water can freely circulate over all surfaces; and that the water is in large excess.

The seventh method is undoubtedl good, but requires mechanical action to keep the surface of the carbide in contact with the other active material, or very finely granulated carbide.

These methods are stated as nearly as possible in the order of their numerical importance as represented by existing generators. If preferred, the second may be looked upon as a bad example of the sixth, and the third as a bad specimen of the fourth.

The next consideration in designing an acetylene generator is that of freedom from any liability to dangerous conditions. This will be treated of in a later chapter. It is sufficient to say here that there is no necessity for any acetylene apparatus to be more dangerous than a gas-meter or oil lamp.

The only other point that needs particular study in design is that of simplicity and ease of manipulation. The great importance of this is seen when we consider that probably the largest field for acetylene lighting is that of country houses, where the apparatus is generally attended to by a domestic servant or labourer. Mechanism of any kind is more or less out of place, as a breakdown cannot be allowed for, and mess or trouble in cleaning or charging would soon disgust the user.

For this reason, any method used for automatically controlling the supply of water to the carbide or carbide to the water must be absolutely simple, practically incapable of getting out of order, thoroughly obvious in its action, and easy to repair on the spot.

The cleaning of the carbide chamber must be performed without any handling or digging out of the lime, and the charging must not necessitate more handling of the carbide than can be done expeditiously by a trowel or tongs.

CHAPTER IV.

GENERATOR DESIGN.

FROM a study of the general principles of acetylene production treated of in Chapter III. it will be seen that success depends not upon the type of apparatus, but upon some of the apparently minor details of construction, and methods of charging and working. In the following it is intended to illustrate the more obvious means for carrying out these principles in construction and ensuring the proper working of each type of apparatus, taking them in the order given in the suggested classification of the preceding chapter.

The type of generator shown in Figs. 13 and 14 is probably the most widely represented on the Continent and in America on account of its great simplicity in construction and use. The principal objections to it raised by opponents are, that owing to the large bulk of water used, and the method of charging, an appreciable portion of the gas is wasted, and when used on the "automatic" system the mechanism necessary for feeding in the carbide is out of place in any domestic apparatus, where a breakdown cannot be allowed for, and any temporary stoppage would cause so much trouble.

The small waste of gas is not of any great importance in a private installation, and may be reduced to within the limits of that of other types by careful working and correct design of apparatus.

The principal points to be considered in the design of this type are—

(1) Provision must be made to keep the carbide surrounded by freely flowing water.

(2) The carbide must not fall into thick lime sludge.

(3) Provision must be made for clearing the sludge cock or other cleaning valve from lime or solid pieces of crust should it become stopped.

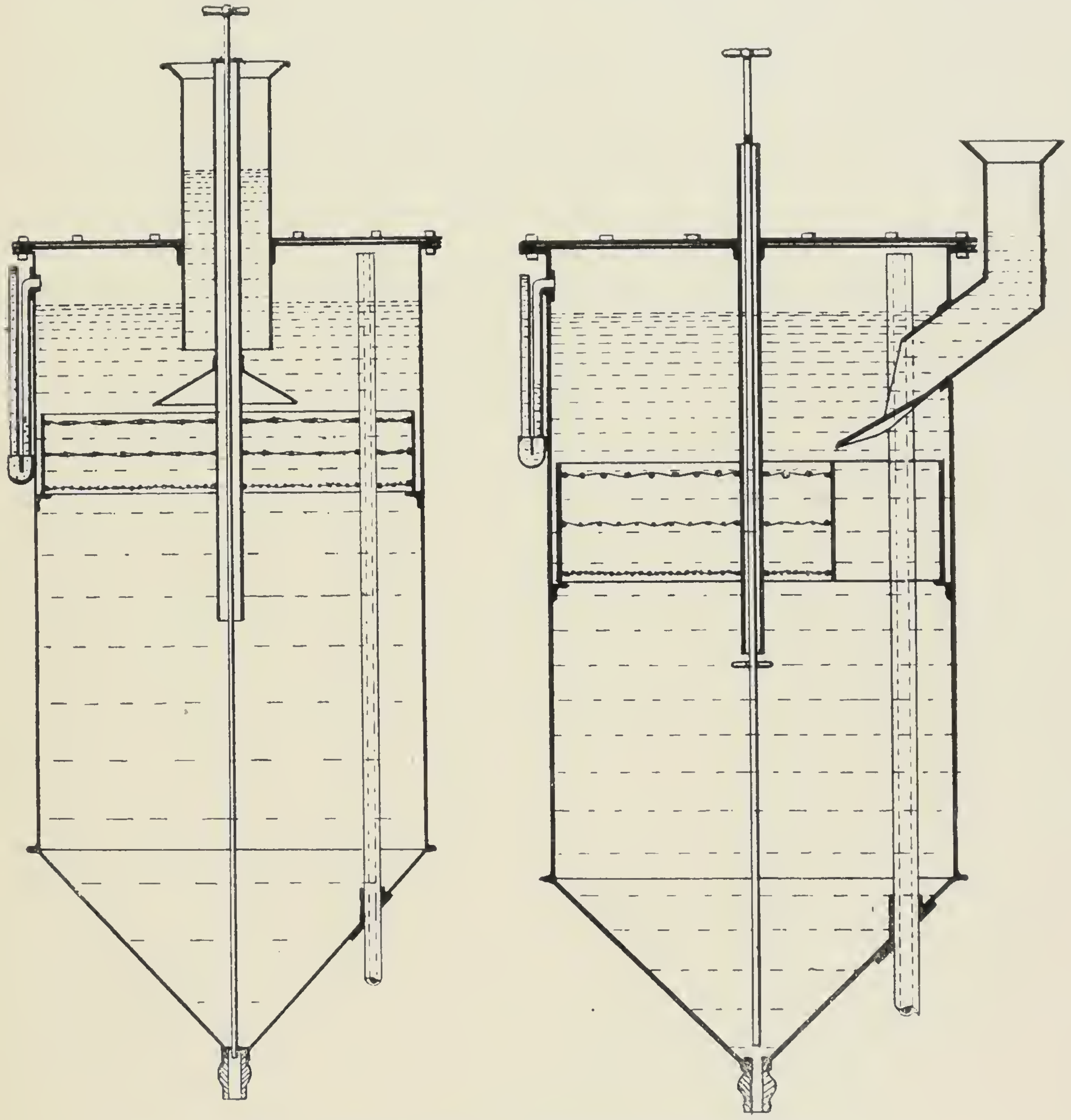
(4) The greater portion of the acetylene-saturated water should be saved and only the thick sludge run off.

(5) The pipes leading from generator to gasholder must be fully large enough to take the sudden rush of gas from the maximum charge that can be fed in at one time.

(6) Provision should be made for easily removing the top of the generator and the grids for cleaning purposes.

Other points will be observed on studying the drawing. The height of the carbide feed pipe is governed by the pressure of the gas, and where a constant water supply is not at hand, it should sink deep enough to allow for the amount used in the production of gas.

In the apparatus illustrated the carbide is kept in a current of quickly moving water by the use of three grids, the upper of $1\frac{1}{2}$ in., and the second of $\frac{3}{4}$ in. to $\frac{1}{2}$ in. mesh. These two grids serve to separate the carbide, the upper only arresting the larger pieces and dispersing the smaller over the lower. The third grid is of much finer mesh, $\frac{1}{8}$ in. to $\frac{1}{16}$ in., and is used to catch the pieces of carbide falling from the second as they become reduced in size. It may appear somewhat unnecessary to use three; but owing to the tenacity of the lime adhering to the carbide it requires some shaking to make it pass a grid of small mesh, and were any considerable portion of the carbide to fall on one spot on a grid of even $\frac{1}{4}$ in. mesh it would have a tendency to form a more or less solid mass, and as the top grid has undoubtedly a beneficial action in dispersing the carbide, especially when fed in quickly, we can hardly dispense with any one of them without some loss of efficiency.



FIGS. 13 AND 14.—HAND-FED "CARBIDE-TO-WATER" APPARATUS.

By keeping the grids near the top of the generator a large bulk of lime sludge may be allowed to collect before it is run off, thus saving as much as possible of the dissolved gas by only permitting the thickest part of the sludge to escape when recharging.

To permit of the easy removal of any obstruction in the sludge cock the top of the generator or the valve used for the admission of the carbide (Fig. 13) may carry a tube, extending below the grids (to prevent any escape of gas), through which a rod may be passed directly through the bore of the cock. Should the bottom grid not arrest all of the carbide this rod may have a disc attached below the tube (Fig. 14) to deflect any bubbles of gas past the opening. The rod must then remain in the generator and have a projection at the top to catch the side of the tube and suspend it above the cock when not in use.

The carbide is fed in by hand in quantities of one to four pounds at a time according to the capacity of the apparatus, and must not be in larger pieces than would pass a screen of 2 in. mesh.

The admission tube should be placed over a cone as in Fig. 13, or should end in a *flat-bottomed* chute as in Fig. 14, which should be made to serve the two purposes of distributing the carbide over the grid and of deflecting the stream of gas away from the opening. The depth of water in this tube should be no more than is absolutely necessary, so that the carbide may lose as little as possible of its gas in falling through.

The only dangerous conditions that can be found with this type of generator are when the water has been run down below the carbide feed pipe. The air can then enter and mingle with the gas remaining in the apparatus, or given off from the water, and form an explosive mixture which may be ignited by a flame or burning cigar held over the top.

To prevent the possibility of such an occurrence the generator may be connected up with a permanent water supply through a ball-cock, so that when the sludge is run off it is automatically filled while the attendant is on the spot. This method also has the advantage of keeping the water level constant and reducing the otherwise necessary allowance in the dip of the chute, or feed pipe, for change or level.

Some makes of carbide will give rise to a considerable quantity of froth in an apparatus of this class, but need not be a source of trouble unless the exit pipe is too small or liable to become choked.

In production of gas the second type of the "quick action" class of generator shown in Figs. 15 and 16 is exactly the same as the preceding, but for particular conditions of use it has some distinct advantages :—

(1) It is particularly suited to automatic control and is undoubtedly the best for this purpose where a large number of lights are required.

(2) Where a battery of generators is used waste of gas through solution or any cause may be practically eliminated.

(3) Any addition to the capacity of "automatic" plant may be made inexpensively and without trouble, as the unit size of gasholder can control any number of generators.

In considering this generator (Figs. 15 and 16), the warning is necessary not to confound it with the very many specimens of similar outward appearance but entirely different principle. The difference may usually be detected in the relative amount of space given to the carbide and water.

The points to be considered in the design of this type of apparatus are :—

(1) The amount of water in the generator at any time must be four times the amount of the carbide that has been in action.

(2) The carbide must be so placed that the water can freely circulate below and on all sides of each lump.

(3) The size of each generator is

controlled only by the unwieldiness of the lid, and the size of the gasholder when used on the automatic system by the amount of carbide in a single generator only.

(4) The size of the pipes leading from the generators to the gasholder should be large enough to take the full amount of gas that would be given off if the water were run on continuously and quickly.

(5) The lime should leave the carbide baskets and settle to the bottom of the generator.

In the apparatus illustrated in Figs. 15 and 16 the carbide baskets are made of wire of about $\frac{1}{2}$ in. mesh and are only deep enough to hold the correct amount, which in the larger sizes should be in lumps of about $1\frac{1}{2}$ in. and not more than one lump deep. If the full charge is required smaller carbide should not therefore be used.

When set up in a battery of two or more they are more conveniently run in series, as the water in the first which holds a certain quantity of gas in solution is then run into the second, and finally into the last of the series, thus reducing the waste of gas to the absolute minimum.

There is no advantage in running a battery in parallel, as with sufficiently large pipes each unit may be discharged as quickly as the gas can be given off.

When used on the automatic system the piping should be so arranged (Fig. 16) that one half the battery may be cut out for recharging while the remainder is in use and the flow of water directed from either end. This is not a matter of importance ordinarily, but is so easy of accomplishment that it may as well be arranged for.

When the water enters the top of the generator it should be deflected to the bottom of the vessel by a shield which may be part of the carbide holder, and not allowed to flow on to the top of the carbide.

The residue is run off from a cock at the bottom of the apparatus. Shaking the carbide holder in the water before it is run off should clear the trays of all lime.

The gasholder in use with a battery worked automatically should be of sufficient size to hold the gas from one-half of the charge of one generator; but where one generator only is used and the greater portion of the gas is consumed each night the holder need not be larger than that sufficient to hold the gas from two of the trays of carbide. But the "golden rule" is *the larger the holder the better.*

At each fall of the holder sufficient water should be run in to completely flood one tray but not attack the next. This can be accomplished by adjusting the capacity of the "control" cock and the quickness of the cut-off.

With this form of apparatus it is difficult to imagine any source of danger in ordinary working provided the gas pipes are of sufficient size and the shed is properly ventilated. It might be possible to explode part of the apparatus, by applying a light to the sludge cock or to any opening in the apparatus provided that the lids of the generators were still on and the air had not been cleared out or had been introduced by drawing off the sludge without first taking off the lid. Even this remote contingency might be provided against if thought necessary by keeping each generator separate and by connecting the sludge cock with a drain pipe properly trapped.

The height of the gaspipe leading from the generator above the hydraulic main or other water seal should be greater than that of the top of the generator over the bottom of the drain-pipe, or otherwise if the sludge is drawn off without removing the lid of the generator the water from the water seal and afterwards gas will syphon out.

The type illustrated in Figs. 17 and 18, often known as the "drip," has quite undeservedly come into disrepute owing to an attempt on the part of the makers to produce the gas too quickly from a given weight of carbide.

The scope for this type of generator is in filling à large gasholder slowly during the day as well as while using the gas, and on the automatic system in running a small number of lights for a considerable time or with long periods of rest.

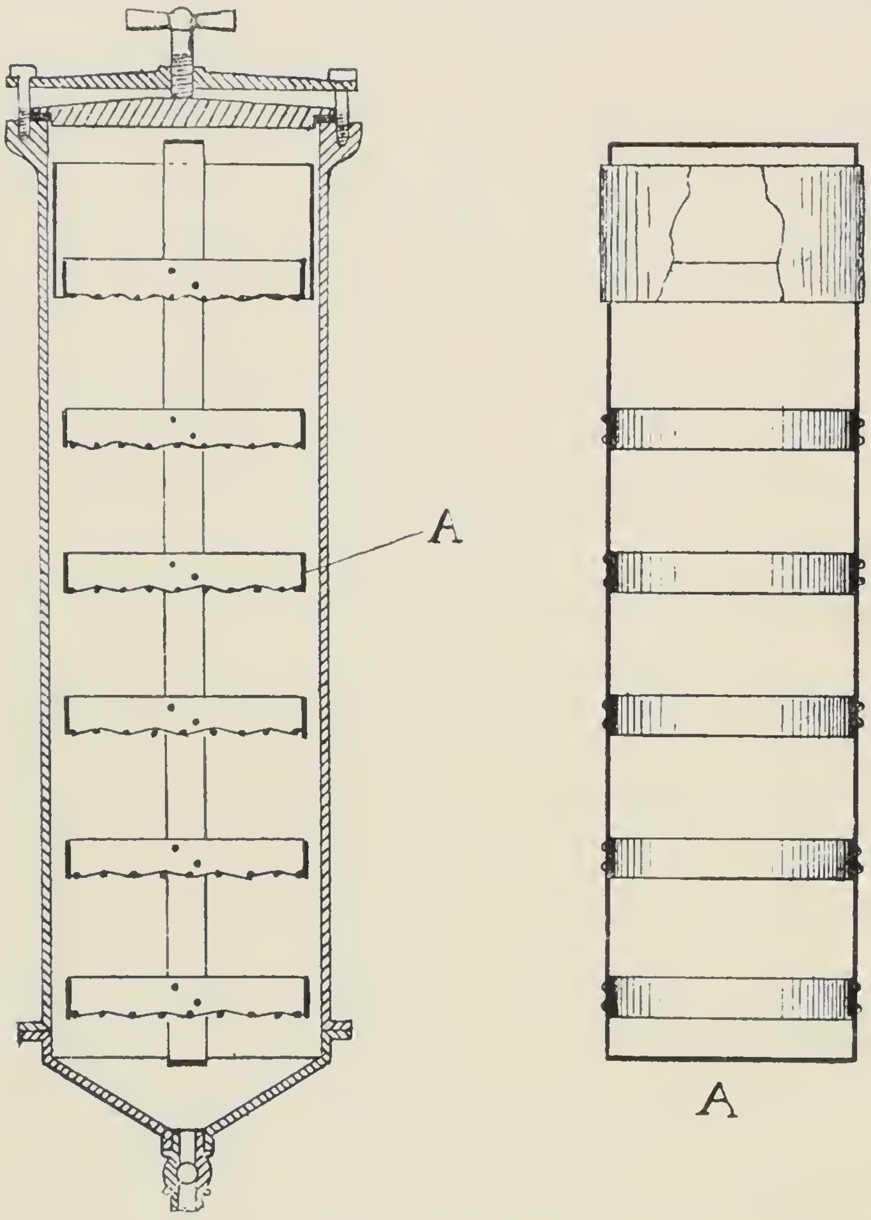


FIG. 15.—"WATER-TO-CARBIDE" APPARATUS, WITH WATER IN EXCESS; A, CARBIDE BASKET.

Its advantages for these particular objects are—

(1) It requires less attendance than the "carbide-into-water" type. A generator may be charged with a hundredweight of carbide in a few minutes and then left to slowly fill the holder.

(2) The gas being produced very slowly may be purified with smaller charges of material and less expensive apparatus. All piping up to the gasholder may be reduced in size, and the use of any special drying apparatus is unnecessary.

(3) The lime residue may be removed in a practically dry condition, and in this form is in many places of some value.

(4) When working on the automatic system there is no large excess of water to cause overmake or other troubles when the generator is shut down for any length of time.

When this type is better understood it may be expected in many situations to supersede all others for very large duties where a full-size gasholder is employed, such as in village lighting, etc.

The principal considerations in designing this form of generator are—

(1) The water must be fed in so slowly that the lime in contact with the carbide *never becomes wet.*

(2) The carbide must not be more than one lump deep, and not packed closely if the lumps are large.

(3) If more than a few lights are required a very large surface of carbide must be attacked at once.

(4) The size of gasholder required for automatic working is governed by the amount of moisture remaining in the lime when three-quarters of the charge is used.

Owing to the large surface of carbide required by this method, the generator, if of cylindrical form, should be placed horizontally (Fig. 17), or when required for large duties may take the form of a wide tank with water-sealed cover (Fig. 18). The water seal may be formed by the water used for .the production of the gas, but is preferably separate, as in the drawing.

The flow of water into the carbide chamber should not be quicker than one pint per hour for every 200 square inches of surface, and a still smaller quantity is preferable. With any but the larger sizes of apparatus, therefore, the hole through which the water is supplied is so small that precautions must be taken to prevent a stoppage by filtering the water through a fine strainer or sponge over the supply pipe, and to make use of the largest possible opening the head of water may be reduced by placing a supply tank only a few inches above the generator.

This tank, if made to hold just sufficient water for the amount of carbide in use, will prevent the flooding of the lime residue, so that it may be withdrawn practically dry.

The bottom of the carbide basket should admit water over the whole surface at once, and must therefore be raised slightly above the bottom of the generating chamber to allow the water to flow from one side to the other.

The carbide used should be of sufficient size to constitute a full charge when not more than one lump deep in the basket, and if larger than 2 in. should not be packed closely.

Where the water drips on to the top of the carbide provision should be made for a free escape of gas and vapour at the sides or bottom of the tray when any quantity of carbide is used, and the drip must be well distributed over the whole surface if the maximum amount of gas is required in a given time.

When working a battery of this type of generator in series automatically controlled by a small holder, a little difficulty is presented by the length of time required after the action in the first has ceased for the flow of water to pass through into the second.

This may be overcome almost entirely by allowing the water to drip on to the bottom of one end of the carbide chamber and to flow out at the other end (Fig. 17) at nearly the same level, the carbide tray resting on the bottom of the generator. By this means, as soon as a thin layer of lime is saturated with the water it will pass into the second chamber without soaking the whole of the lime in the first. By careful adjustment the second chamber may be started before the first is quite exhausted.

In ordinary working no dangerous conditions can be found in the above apparatus. The conditions requisite for an explosion would be the same as in the case of the last-mentioned "quick action" type of generator.

Within the writer's knowledge no successful generator of the second type of this class of apparatus, in which the water is supplied by means of another solid, has been placed on the market, though one is shortly promised.

The substances used may be—

(1) Salts containing water of crystallisation.

(2) Organic substances containing water.

(3) Porous material holding or acting as conveyor for the water.

The object aimed at in most experiments with this type has been the use of a substance that would leave the residue in the form of a marketable product.

The advantages offered by the type of apparatus in which the action is controlled by oil (illustrated in Fig. 19) are:—

(1) An almost perfect control over the production of gas.

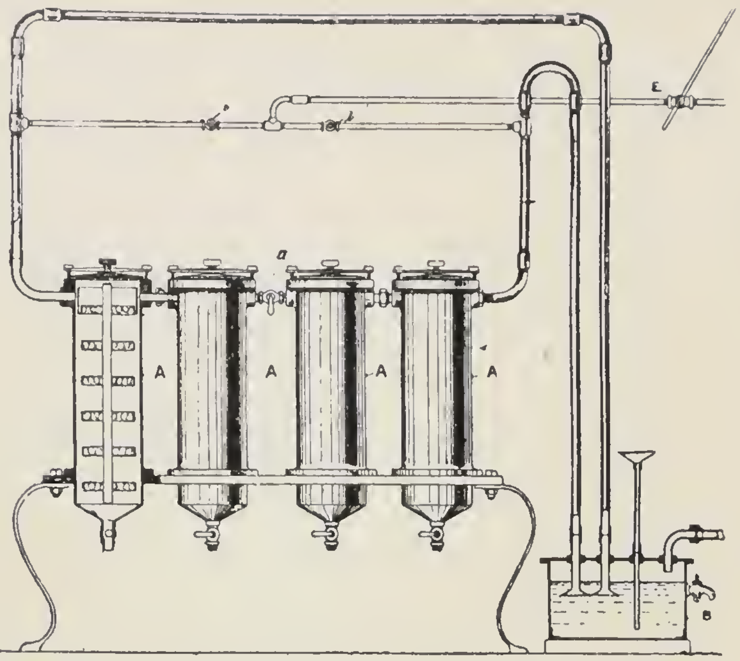


FIG. 16.—ARRANGEMENT OF PIPING FOR "AUTOMATIC" WORKING AND EASY EXTENSION OF PLANT WHILE RUNNING.

(2) The absence of all moving parts and of any separate gasholder, when used on the automatic system.

(3) Very large capacity in a small space.

In this apparatus the carbide is suspended in a cage over a body of water carrying a sufficient layer of paraffin, or other suitable oil, floating on the top. More water is then run in until it rises into contact with the carbide, and gas is produced at the required rate.

The duty of the layer of oil is to prevent the action extending above the bottom surface of the charge, which, being constantly bathed in water, cannot overheat so long as the lime is removed as quickly as it is formed.

This generator is "automatic," provided that the water is free to rise and fall, without any additional apparatus or gasholder, seeing that should the gas be produced faster than it is consumed, the water is pressed down, and the oil following practically waterproofs the carbide over which it passes. This takes place so perfectly that under satisfactory conditions no variation in the pressure of gas is noticed while the apparatus is working.

The difficulties to be overcome in designing the above apparatus are:—

(1) The vapour given off from the oil must be thoroughly scrubbed out of the gas, if it is to be used in the ordinary way.

(2) The basket must be so made that the lime always falls away from it as quickly as produced.

(3) The oil used should not be run out with the lime sludge, and must not be liable to "blow" out with any escape of an "overmake" of gas.

The first difficulty is the greatest, and can only be overcome, firstly, by using an oil that contains no hydrocarbons of low boiling point; secondly, by carefully cooling and scrubbing out any vapour before the gas enters the purifier; and thirdly, by keeping the temperature very low. If this is not done the purifier will very quickly become useless, except for scrubbing out the oil vapour. A liquid purifier might overcome this part of the difficulty, but would allow the oil vapour to pass on to the burners.

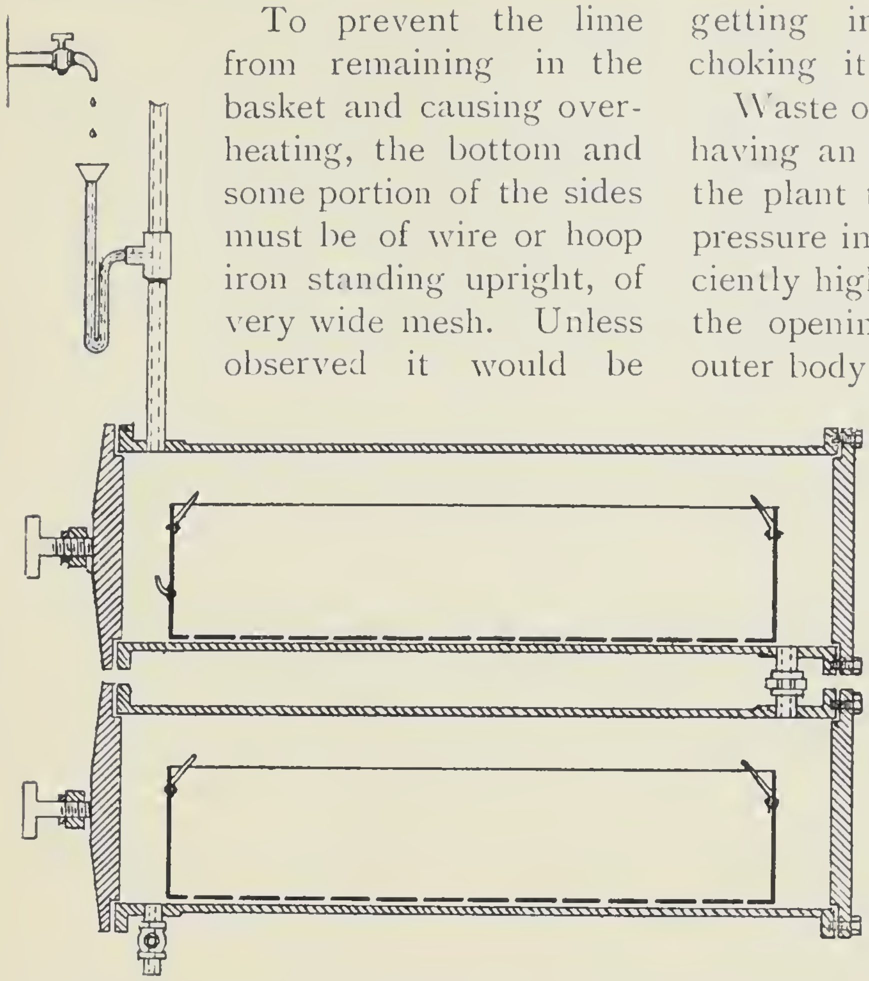


FIG. 17.—"SLOW CONTACT" ARRANGED FOR "AUTOMATIC" WORKING.

To prevent the lime from remaining in the basket and causing overheating, the bottom and some portion of the sides must be of wire or hoop iron standing upright, of very wide mesh. Unless observed it would be difficult to believe that the lime would possess so much tenacity as it shows in these baskets, and as the instant removal of the lime is the sole prevention of overheating, too much importance cannot be attached to this point.

In addition to which it is necessary to use very large lumps of carbide, which must not be packed close together, and the proper working is greatly helped by thoroughly soaking the carbide in the oil before it is used, so as to prevent any action taking place above the bottom surface of the lumps.

The openings in the bottom of the basket being very wide, it is advisable to place a grid of smaller mesh below, to catch the small pieces of carbide as they drop through, and prevent any slag or cinder getting into the sludge pipe and choking it.

Waste of oil should be prevented by having an escape pipe in some part of the plant that will blow off before the pressure in the generator becomes sufficiently high to cause the oil to fall below the opening communicating with the outer body of water, and when running off the sludge the water should not be allowed to fall below these openings for the same reason.

If while working the oil is allowed to flow out of the generating chamber, its controlling action will be lost, and over-heating of the charge result.

The form of generator illustrated in Fig. 19 is absolutely safe so long as oil is used or the carbide is soaked in oil, provided, of course, that a light is not applied to any opening while air is mixed with the gas: such as to the cock in the cover on starting the apparatus, or to the sludge cock after emptying it while the cover is still on.

If the oil were not used, and at the same time the carbide were not soaked in oil, it might be possible for a large charge of comparatively small carbide to so overheat as to ignite the mixture of air and gas present in the automatic form of this generator while the action is being started. By only having sufficient

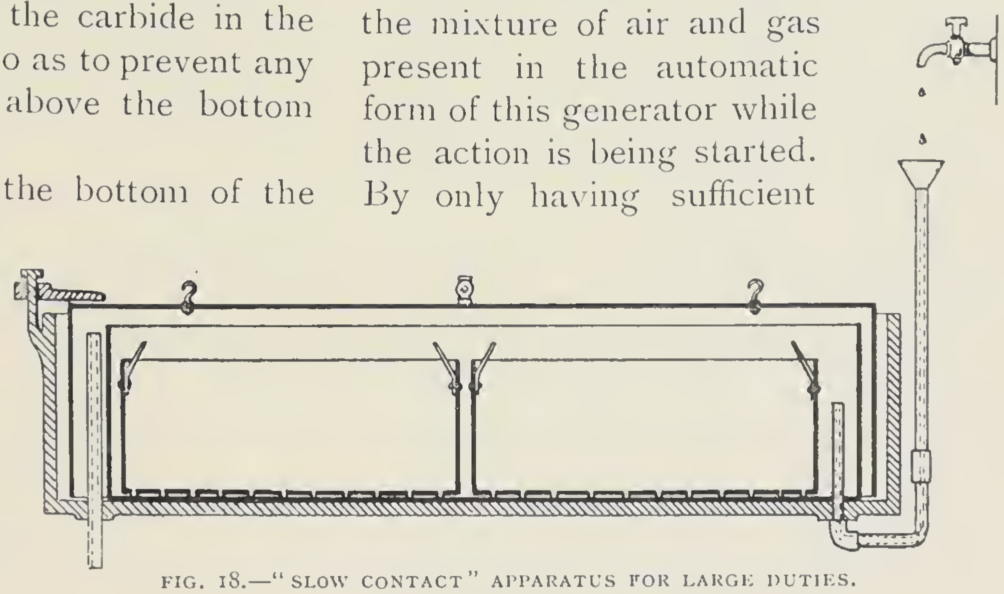


FIG. 18.—"SLOW CONTACT" APPARATUS FOR LARGE DUTIES.

room for the charge in the carbide chamber, even this possibility of danger may be avoided.

In action and general principles of construction the type shown in Fig. 20, in which a lime solvent is made use of, is the same as the last, but without some of the objections that may be urged against the latter.

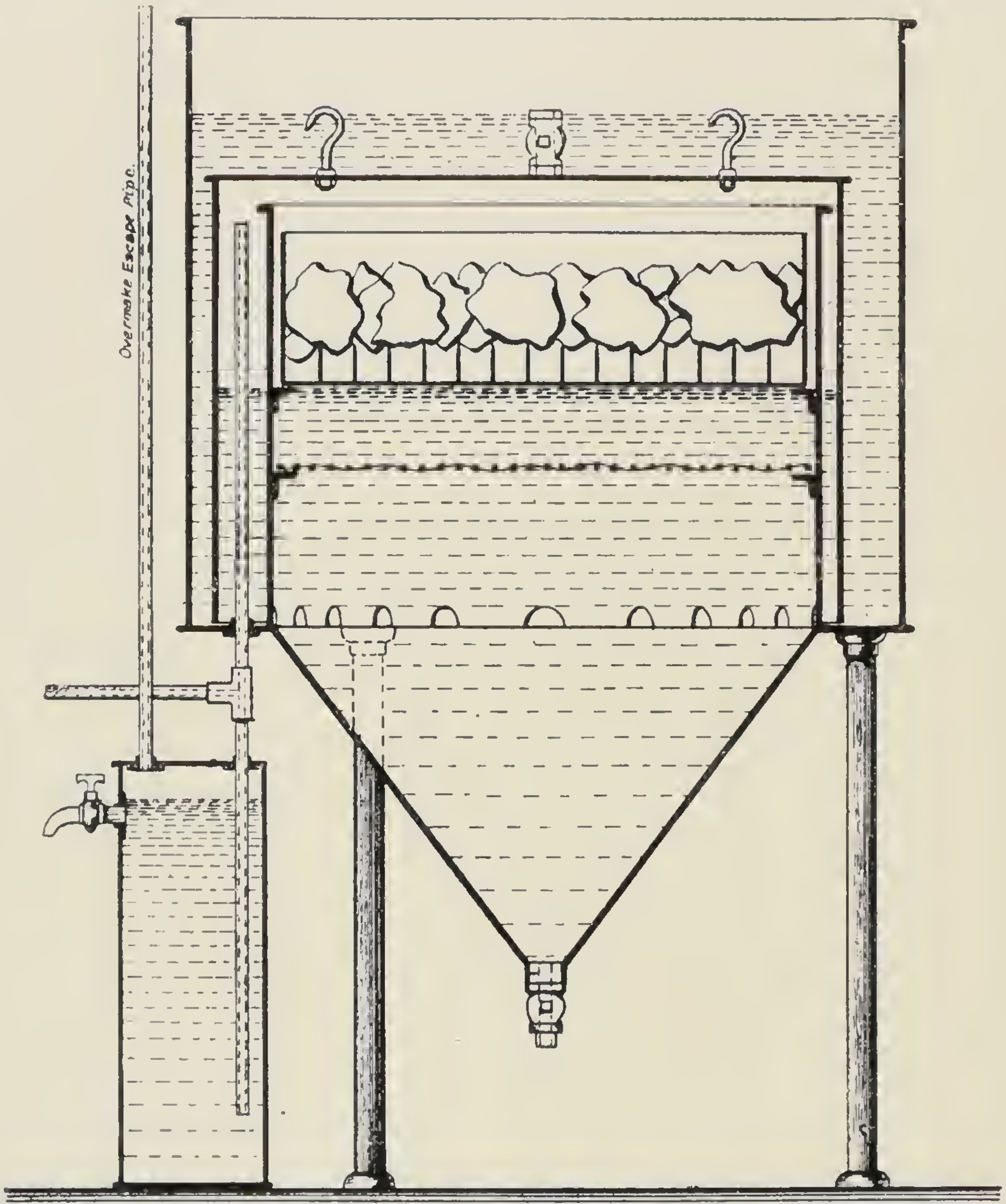


FIG. 19.—GENERATOR, IN WHICH ACTION IS CONTROLLED BY OIL.

The solvent generally used is sugar or glucose, and in order to reduce the amount required it is usually applied in the form of a coating on the carbide. In addition to this there is generally a small quantity of some hydrocarbon that waterproofs the lumps of carbide, and protects them from the action of moisture until they are immersed in water.

The usual method is to soak moderately small lumps in paraffin, and then apply a hot coating of sugar or glucose, which becomes solid and dry on cooling.

The amount of glucose is not, as a rule, sufficient to dissolve the whole of the lime, but as it is, by the above means, dissolved gradually by the water, and applied continually at the spot where the action is taking place, it is enough to prevent any accumulation of lime, and to keep the surface of the carbide clean.

The oil has its duty in preventing the spreading of the action above the lower surface of the carbide by the moisture and spray carried up by the gas.

To prevent any great variation in pressure, the surface of water outside the carbide chamber should be larger than that of the inside.

The only objection to this form of apparatus would be the extra cost of the treated carbide, which practically restricts its use to lamps and small generators for "lantern" displays, etc.

In any acetylene apparatus it should be looked upon as essential that the gas pipe leading into the holder should be water-sealed in such a way that gas cannot return from the holder to any part of the apparatus that may be opened. For this purpose a small hydraulic main, a "water-lock" as it is sometimes called, should be used.

It is unwise to trust to a cock which the attendant may forget to shut off, but a valve or cock is a useful addition after the waterlock, and should not be neglected where a large holder is used, otherwise the waterlock or pipes cannot be repaired or altered without emptying the holder.

The pipes leading into each storage-chamber, of whatever kind or size, and from one generating chamber to another, having independent water-feed, should be sealed in this way, so that no quantity of gas can escape on opening any one generator of a battery.

In the waterlock or hydraulic main a cock should be provided for keeping the water level at the required height, and where it is also used as a scrubber, a filling tube or plug for running in fresh water, and a cleaning plug at the bottom or side for removing any lime frothed or sprayed over from the generator, may be necessary.*

If preferred, petroleum or other oil may be used in place of water, and in this case another cock will be required at *the bottom* to run off condensed water.

It ought also to be considered necessary that there should be an escape pipe or safety-valve immediately after any closed-in generator, and before any cock for shutting off the gas. Without an escape pipe or open water-seal it would be possible to shut in the carbide and water in the generator, and convert it into a miniature bomb.

The gasholder is a sufficient safety-valve where there is no cock between it and the generator, and where a cock is used in this position, the "waterlock" may be converted into a safety-valve by making it with a water-sealed cover, or by using an open "filling tube" of sufficient capacity, as shown in Fig. 21.

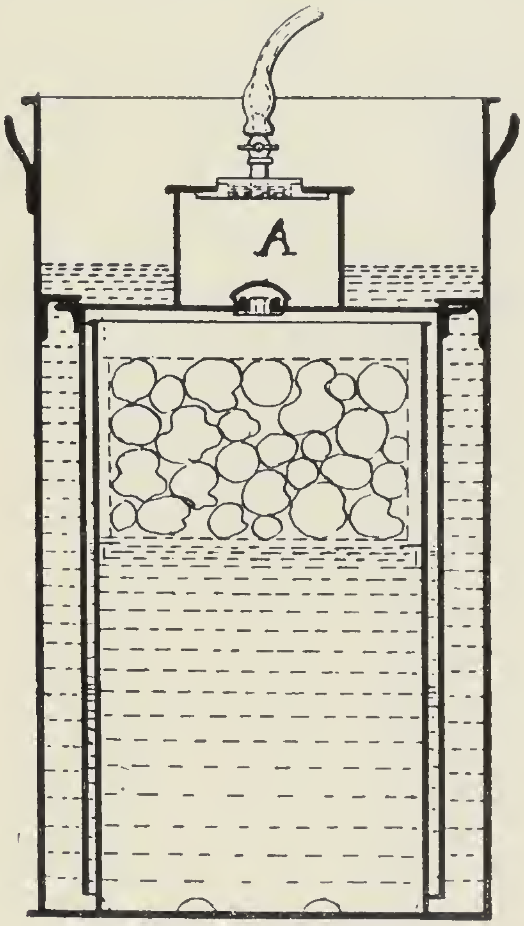


FIG. 20.—GENERATOR IN WHICH ACTION IS CONTROLLED BY A LIME SOLVENT; A, DRYING OR PURIFYING BOX.

FREEZING.

It would be possible for frost to cause a complete stoppage of the pipes

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* This plug must of course never be removed nor the water run out while there is gas in the holder, unless there is a cock between hydraulic main and holder.

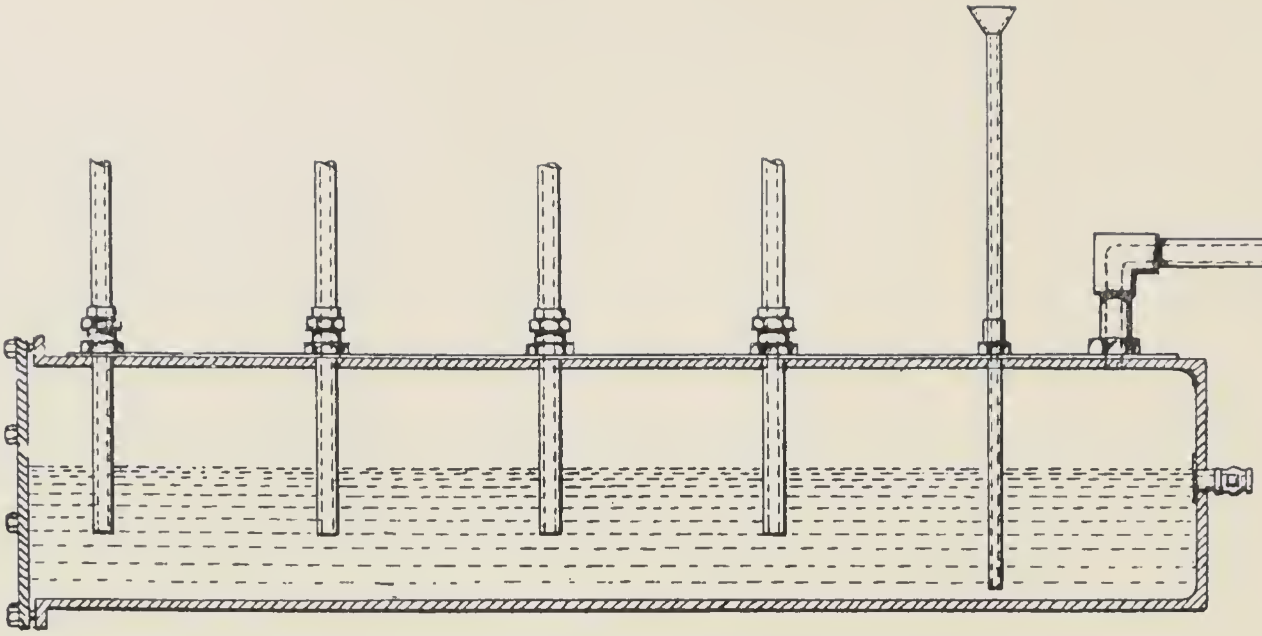

FIG. 21.—HYDRAULIC MAIN FOR FOUR GENERATORS.

leading from the generator, and consequently risk of an explosion with any apparatus in which the carbide is contained in a sealed chamber.

To prevent any accident happening from this cause, a little care is necessary in the fitting up or working of the apparatus. Freezing of the pipes may be prevented if moisture is not allowed to collect in them, by providing a drip chamber at the lowest point that will hold some considerable accumulation of water without filling the pipe.

All danger from freezing may be obviated by filling the hydraulic main or waterlock with a 25 per cent. solution of calcium chloride or with paraffin, and providing an escape pipe sealed only by the liquid, such as the filling pipe in Fig. 21. The gas-pipes should, of course, enter this waterlock direct from the generator without any bend that could hold condensed moisture.

The freezing of the water seal of the gasholder may be prevented by using a 20 per cent. solution of calcium chloride, but as this substance is not without suspicion of corroding the iron, it is perhaps better to surround the tank with hay bands, spent tan, or similar material, and should any ice form on the top, to thaw it out with boiling water before starting the apparatus. In any case this should be sufficient in such a climate as that of Great Britain.

Freezing could hardly take place in England so long as the apparatus is producing gas, and where only a few nights are sufficiently frosty to cause any trouble, arrangements might be made to keep the generator at work.

The water supply pipe may be prevented from freezing if it obtains its supply from a separate tank in which a few handfuls of calcium chloride or common salt can be thrown and some allowed to run into the pipe, any night on which a severe frost may be expected.

CHAPTER V.

PURIFICATON OF ACETYLENE.

VERY early in the history of acetylene lighting it was found necessary to remove from the gas produced by carbide and water certain impurities which are responsible for most of the objections that have been raised to its use.

A great improvement in the purity of carbide has been used as an excuse for neglecting this precaution in many installations, much to the disadvantage of the industry. So long as acetylene contains phosphorous compounds to the extent of even so low as ·03 per cent., and probably much lower, it will be possible to detect it by the sense of smell in a closed room where the unpurified gas is being burnt.

Although it may be granted that unpurified acetylene is not so objectionable as ordinary coal-gas, it must not be forgotten that we are used to the smell and other disadvantages of coal-gas and have acquired the habit of not noticing them, while with impure acetylene the entirely new difficulties or unpleasantnesses to which we are not at the moment willing to become reconciled are sure to be magnified, and cannot help being noticeable.

Admitting that in time we might be more than willing to put up with the comparatively smaller disadvantages of the use of unpurified acetylene, it would not only be a step backward, but one which the industry could not afford in its present stage.

The impurity to which these remarks particularly apply is the phosphuretted hydrogen, with which may perhaps be included a small proportion of other phosphorous compounds. It is generally conceded that phosphorus is the cause of acetylene "fog," and it is also the cause of the noticeable odour arising from burning the unpurified gas, the sulphur generally existing in too small a quantity to have any effect comparable with that of ordinary coal-gas.

The phosphorus is also the most difficult to eliminate, and as the ordinary materials used for its removal take away at the same time all other harmful impurities, it is therefore the first to be considered.

The substances which can be used to remove the phosphorus are very limited in number, owing to the necessary requirements of such a material, which are:—

1. It must not have any appreciable action upon the acetylene.

2. It must be inexpensive in use.
3. It must be easily applied.
4. It must not admit of the formation of acetylides or any explosive products.

The materials in use for this purpose are chloride of lime, an acid solution of cuprous chloride, and chromic acid solution, the two latter generally absorbed in kieselguhr.

Each of these will remove the whole of the phosphuretted and sulphuretted hydrogens and fulfil the above requirements if properly used.

The chloride of lime should be mixed with broken-up coke or pumice, or it will be liable to pack and prevent the passage of gas through the body of the material; it should also have an addition of 25 to 50 per cent. of fresh lime to retain the whole of the chlorine, and is greatly improved by the addition of about 10 per cent. of anhydrous calcium chloride.

If prepared in this way, or if the special preparations known as "puratylen" and "calchlor" are used, the ignition of the acetylene on opening the purifying chamber, which sometimes happens with chloride of lime, need not be feared.

It is possible for the ammonia present in acetylene to form the explosive compound chloride of nitrogen when in contact with moist chloride of lime, but as this has only been found in a very few instances and in very small and practically harmless quantities, it has not been put forward as a serious objection, especially as all possibility of danger from this source can be obviated by washing out the ammonia first.

Chloride of lime used alone should be followed by a purifier containing lime only to absorb the chlorine compounds carried over with the gas, or the pipes and fittings may suffer.

When using cuprous chloride, it is very necessary that there should be sufficient free acid to neutralise the whole of the ammonia allowed to pass into the purifier, otherwise an explosive compound of copper and acetylene may be formed, which might make the exhausted material a source of danger.

As placed on the market under the name of "Frankolin," this material usually contains a sufficient excess of hydrochloric acid to deal with all the ammonia that the gas can carry with it, even in the worst of the generators.

This material has the objection, in common with ordinary chloride of lime, of giving off a corrosive vapour, in very slight quantities undoubtedly, but still sufficient to arouse a suspicion of its destructiveness on the fittings and taps. An excess of water with the liquid used to impregnate the kieselguhr might obviate this trouble, and a lime purifier would certainly remove it.

The use of an acid solution of cuprous chloride is due to Herr A. Frank, of Charlottenberg. The substance suggested by Dr. Ullmann, of Geneva, chromic acid, is one which has no properties which can make it a source of danger; but unless the material is applied in the correct manner, it is not without suspicion of destroying part of the acetylene. The method usually employed is to dissolve the chromic acid in sulphuric or acetic acid and impregnate kieselguhr with the solution. The writer has not had a sufficient experience of this material to speak with confidence, but presumably when sulphuric acid is used, only a small portion of the solution should be mixed with a large bulk of kieselguhr.

Any oil vapour, such as that of petroleum, carried over with the gas, appears to be attacked vigorously by this material.

Seeing that these purifying materials not only remove the phosphuretted hydrogen, but at the same time all other impurities from which it is necessary to free the gas—either by combining with them, or acting as a scrubber—it may be considered unnecessary to make use of any other apparatus for this purpose.

This is certainly not the case with installations of any size, or where the expense of the material or constant attention to the purifier would be an objection. The remaining impurities may be removed by far simpler apparatus, at less expense, and without any of the care necessary in attending to the purifier. To save trouble and expense, this part of the apparatus should be given the smallest possible amount of work, and be protected from the action of the sulphuretted hydrogen, ammonia, water, and oil vapours as far as can be conveniently arranged for.

Except in the generators in which the gas is bubbled through a column of lime water, the sulphur is often present in far larger quantities than the phosphorus, and in this case, where the installation is of sufficient size to justify additional apparatus, a washer containing milk of lime, which may more than double the life of the charge of the other purifying material, is a source of economy.

The same argument applies quite as strongly to the ammonia, which may and should be washed out as far as possible by means of cold water before the gas passes on to the purifier.

The other impurities which are removed by the mechanical action as distinct from the chemical properties of the purifying material are water and light oil vapours, either of which have a tendency to throw the purifier out of action, the water by clogging the material and preventing the easy passage of the gas, and the oil by preventing the proper chemical contact between the active material and the gas.

A generator of the "oil controlled" type on one occasion completely threw out of action a "Frankolin" purifier in two days' use without a proper oil scrubber, and the complaints one hears of loss of pressure through the use of a "Frankolin" purifier are generally caused by an excess of moisture in the gas.

The excess of water vapour, if not deposited in the holder, may be removed by passing the gas through a scrubber *after it has been cooled to ordinary temperature.* By mere scrubbing or washing it is impossible to remove sufficient water vapour unless the gas is cooled, but it may be accomplished while warm by means of a drier containing a substance that combines with water, such as carbide, quicklime, fused calcium chloride, etc.

If a drier of this character is used, the gas should be passed over water on its way to the purifier (through the gasholder is sufficient), or it may prevent the action of the purifying material.

Oil vapours are far more difficult to remove, and may require washing out by means of another oil either non-volatile or of higher boiling point.

Of almost as great importance as the removal of the impurities is the thorough drying of the gas before it enters the service pipes.

Moisture appears to be responsible in many cases for the carbonisation of the burners; so much so, that many of the claims for purity of gas and perfection of generation rest upon nothing more than the addition of an efficient drier to the apparatus.

The troubles caused by condensation in the pipes and fittings are well known in connection with ordinary coal-gas, and may be far worse with acetylene, which, on the other hand, offers the advantages, not yet fully appreciated, of a perfectly dry gas without any extra trouble or expense.

APPARATUS.

The apparatus required for the purification of acetylene depends very greatly on the type of generator and the size of the installation. While with a generator of the "water-in-excess" class it may be necessary to remove the excess of moisture before passing the gas through the purifier, with the "carbide-in-excess" class the gas may be found sufficiently dry; and while with the "automatic water-to-carbide" type, when running a small number of lights, it may be sufficient to pass the gas through the holder on its way to the purifier, it may be found necessary when working at full capacity to use a special scrubber.

Taking the apparatus in the order of its position,. we necessarily start with the washer for the removal of the ammonia and any lime that may be carried over with the gas. This may be merely an enlarged hydraulic main, the ends of the pipes entering it extending just below a perforated plate, so that the gas passes through the water in fine streams.

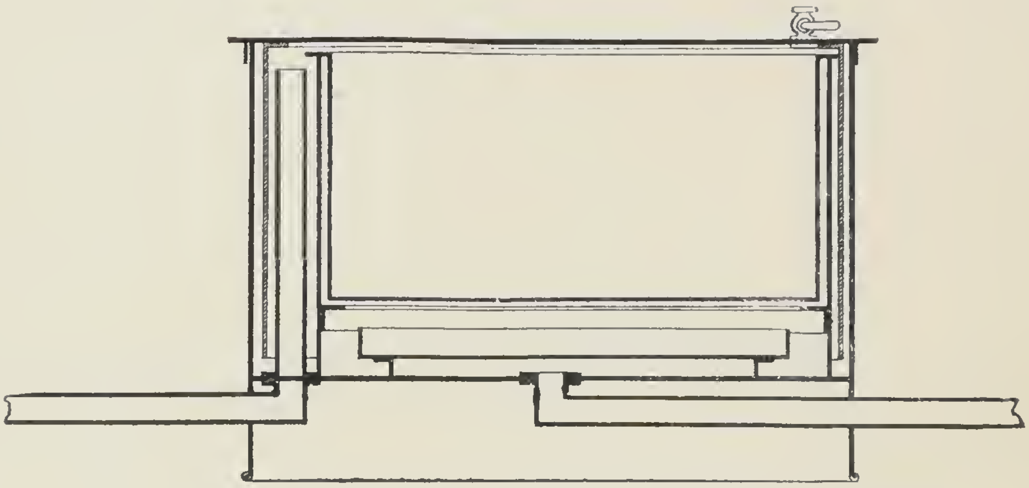

FIG. 22.—WATER- OR OIL-SEALED PURIFIER FOR NON-CORROSIVE MATERIAL.

Though not as effective as other forms, this type of washer uses the least water, and does not, therefore, waste any appreciable quantity of gas. It should not be considered sufficient for large plants unless preceded by a very efficient cooler, such as a long coil of pipe or a shorter coil immersed in flowing water.

Fresh water should be added and part of the old run off every day.

This washer may be advantageously used as a partial purifier for removing sulphuretted hydrogen, by mixing with the water a few handfuls of fresh lime. Part of the spent lime may then be run out each time the water is changed, and fresh added.

In an apparatus of Class I. the gas is generated too quickly for the proper action of the purifier, and it is therefore advisable to pass it into the holder first. By this method, if the holder is of sufficient capacity in comparison with the number of lights burning, the gas will deposit the greater portion of its excess of moisture in the holder and may then enter the purifier.

In a non-automatic generator of Class II., where the gas is produced more slowly than it is used, it is a better plan to thoroughly purify it before it enters the holder.

The most convenient form of cooler is a long coil of iron piping of as small a diameter as will carry the amount of gas required.

If plenty of water can be obtained, it need not be of great length if immersed and constantly bathed in a running stream of cold water. Still water is worse than useless, as a coil immersed in a tank only large enough to contain it merely exchanges its large conducting surface for one of half the area, and would be far more effective if placed where the air can fully play upon it.

The scrubber, unlike the purifier, is most effective when of small area and great height, seeing that its action is mechanical only, and its scrubbing effect is proportional to the number of surfaces it offers to the gas and the velocity with which the gas is forced against them.

The filling material is preferably divided up into two or more portions, so that the lower one may be soaked without affecting the upper.

In an apparatus using paraffin, the scrubbing tower should be of good size and the material used for filling it as fine as possible, and if much benzine or naphtha is present it may even be necessary to wash the gas by bubbling it through some oil, such as heavy petroleum or vaseline oil. In any case, the gas must be absolutely cold before these vapours can be scrubbed out.

All scrubbing towers should have a drain at the bottom, so that the condensed liquid may be drawn off every day.

After the gas has parted with its ammonia, water, and other vapours, it may be passed through the purifier proper, which, next to the generator, is the most important part of the plant.

There are so many difficulties in the way of using a liquid for purifying acetylene that it is hardly ever attempted, and in practice it is almost universal to make use of the absorbent properties of kieselguhr or some similar substance to hold the active material when this is a liquid.

When using cuprous chloride or chromic acid, the containing vessel must necessarily be of earthenware or enamelled iron, but the action of such materials as "puratylen" or "calchlor" on metal is so slight while they are dry that a sheet-iron container is sufficient in all cases.

The purifier generally consists of an outer vessel, in which the pipes are fitted, and an inner vessel to contain the material. It should be wide rather than deep, so that the gas may pass more slowly through the material, which may also be packed tighter without offering any obstruction to the passage of the gas if the container is sufficiently wide.

The efficiency of a purifier is in direct proportion to the length of time the gas is in contact with the active substance, and the slow passage of the gas through a shallow layer of material brings about a much more perfect contact than when it passes quickly through a deep layer.

With any material, the gas should be passed through and not merely over it, unless a very large surface can be exposed, and the gas forced into contact with it by means of "baffles." It will then require frequent renewing or turning over.

In order to use as wide a vessel as possible and add to the convenience in charging, a loose cover sealed by water or oil is a good method of closing the top of the purifier (Fig. 22). It should be noted that when using substances such as "puratylen" or "calchlor," which absorb moisture, oil should be used for the seal.

On leaving the purifier the gas should not contain any objectionable impurities, but when using chloride of lime or cuprous chloride with hydrochloric acid it may be possible for chlorine compounds to be carried into the pipes, and, therefore, for village lighting or very important installations the gas should be passed through lime before it enters the pipes if any suspicion of corrosion or other trouble is entertained.

Where a drier is used, it may very conveniently take the form of the generator shown in Fig. 16, charged with ordinary carbide.

The baskets should be deeper and made of wire, and should touch the sides of the cylinder, so that as the carbide slakes it may fill up the space between the baskets and the walls of the cylinder with lime and force the gas through the middle portions.

The gas should enter by a descending pipe some distance from the bottom of the apparatus, so that the lime that falls from the baskets may be washed out without choking it.

This form of drier should also effectively remove all corrosive vapour or gas from a chloride of lime or "Frankolin" purifier.

"Puratylen," Ullmann's material, or "calchlor" dry the gas as well as purify it when used in sufficient quantity or renewed when exhausted.

In a plant of any importance, where the gas has to pass through a cooler, it is as well to remove the lime that may be carried over into the coil if not intercepted, and in time cause an obstruction or reduce the capacity or conductivity of the pipe by furring the inside.

With the "carbide-to-water" type of generator, the lime would come over in the form of spray or froth, and may be separated by passing it through a short length of 4-in. pipe filled with lumps of coke. Where carried over in the form of dust, a "filter" of much wider diameter is preferable, filled with smaller coke.

A hydraulic main would possibly answer both purposes, but with a water-sealed generator, such as the "carbide-to-water" or the larger type of the "carbide-in-excess," shown in Fig. 19, it is an advantage to keep the required pressure as low as possible, and therefore not to dip the pipe below the water in any piece of apparatus except the washer.

ARRANGEMENT OF PLANT.

The greater part of the effectiveness of the various pieces of apparatus is due to their proper arrangement. To attempt to scrub the moisture out of hot gas, or to place an efficient carbide or other chemical drier in front of the purifier, would be to display a lamentable ignorance of the properties of the apparatus and materials in use.

In private installations there is a good excuse for placing the washer where it is least effective, that is, close up to the generator, seeing that this reduces the amount of apparatus, and the small quantity of ammonia that escapes should not have any very great effect on the purifier; but in very large plants it will be found more economical to place an efficient cooler in front of the washer.

If the following order is adhered to, each part of the plant will be found to give the best possible effect with the least complication of apparatus:—

For small "carbide-to-water," or for "automatic" plants running few lights compared with the capacity of the holder:

Generators.
Hydraulic main and washer combined.
Holder.
Purifier.

For large installations of "carbide-to-water," or for automatic "water-in-excess" plants running at full capacity:

Generator.
Separator or filter to retain the lime sprayed over.
Cooler.
Washer and hydraulic main combined.
Holder.
Purifiers.

For "carbide-in-excess" non-automatic or large installations:

Generator.
Separator or filter.
Cooler.

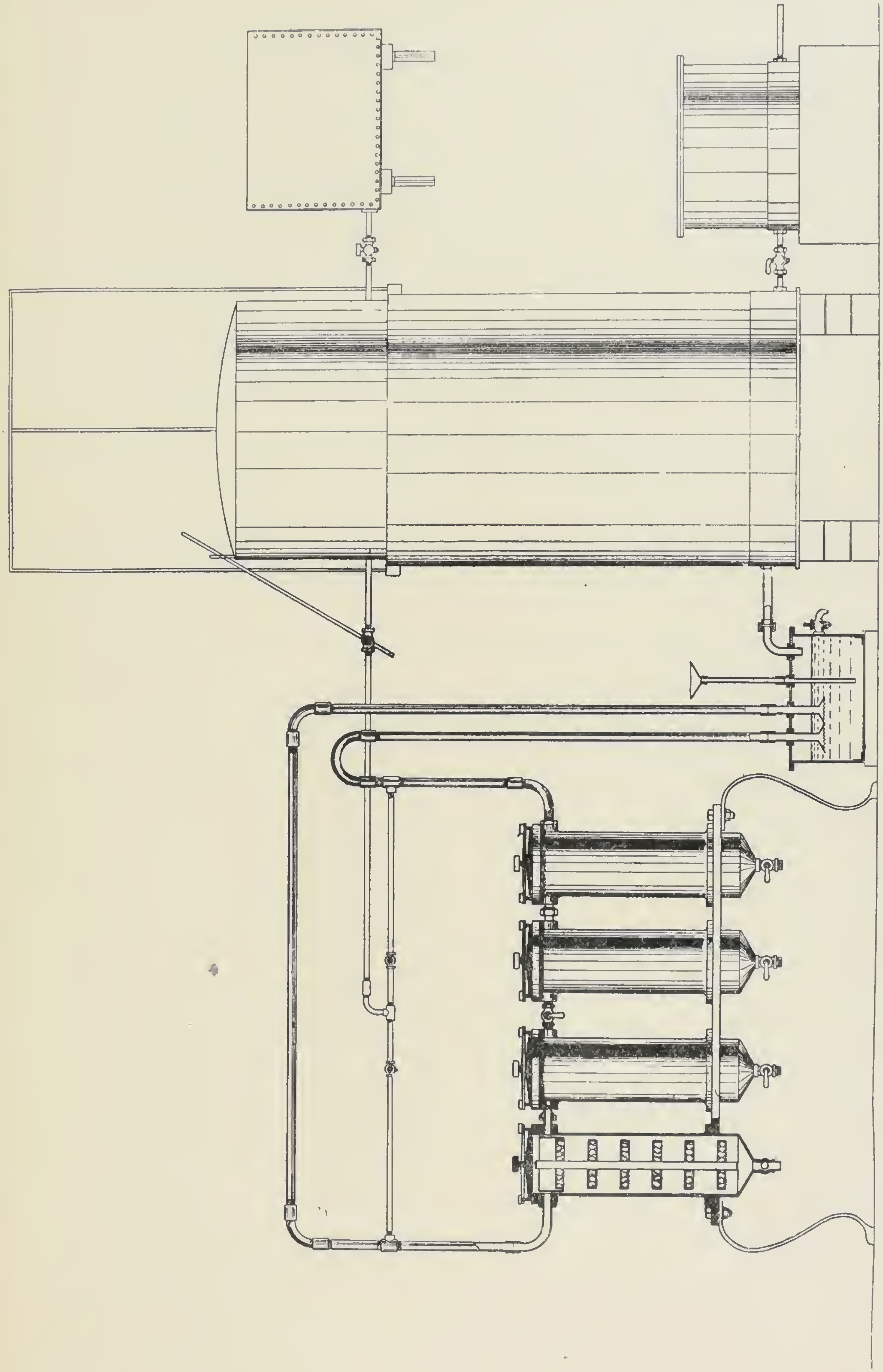

FIG. 23.—40-LIGHT INSTALLATION BY THE ST. JAMES' ILLUMINATING COMPANY, CONSISTING OF GENERATORS, WASHER AND HYDRAULIC MAIN, GASHOLDER, PURIFIER AND WATER TANK.

Washer and hydraulic main combined.
Scrubber (if required).
Purifiers.
Holder.

The last of the three plants offers the advantage of filling the holder with purified gas, prolonging its life, and making it unnecessary to change the water, provided that no chlorine compounds are allowed to pass over from the purifier.

With generators using petroleum with the carbide, an oil washer is probably necessary after the ordinary washer and a scrubber before the purifier in plants of any size. More care must also be taken in cooling the gas before it enters the oil washer.

The same remarks apply to generators that overheat, but it is better to consider these obsolete and have them remodelled or "scrapped."

When using a large and expensive holder, it is better, even with the "carbide-into-water" type of apparatus, to purify the gas before it is allowed to enter. This is done by one of the Continental firms by making use of a smaller holder to regulate the passage of the gas through the purifiers. Although this adds to the expense of the installation, not only by the cost of the additional holder, but also by the necessary increase in size of the purifiers, it is probably an economy. But if by any chance the active material from the purifier can be carried by the gas into the holder, it will probably be far more destructive than the impurities of the gas.

Another important consideration in fitting up the plant is the removal of the products of condensation from the pipes. For a small apparatus, the simplest method is to place the hydraulic main or "waterlock" below the holder with a slight rise in the pipe entering the holder. If the exit pipe is then carried direct into the purifier with a slight "fall" towards the latter, the condensation is satisfactorily dealt with.

For a large plant, it is probably better to have a separate "drip tank" at the lowest part of the installation into which drain pipes from any part of the apparatus may be taken, so long as each pipe is sealed by the liquid in the tank.

If the hydraulic main can be placed low enough, it may be very conveniently used as the "drip tank."

It has often been claimed that an acetylene plant where a large holder is in use gives purer gas than an automatic apparatus, owing to the fact that the impurities have time to settle and are deposited in the holder. This is only true where the "automatic" either overheats or is not provided with proper purifying apparatus.

The holder is certainly not the right place for the impurities, and if the crude gas is allowed to enter it for the sake of economy of apparatus, it should only be after thorough cooling and washing.

It is only in the automatic apparatus with a small holder that is easily emptied and inexpensive to replace that the holder may be looked upon as a cooler and depositing tank, and even this would be bad practice in an important installation.

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CHAPTER VI.

THE ACETYLENE FLAME.

THE very great illuminating value of the acetylene flame is apparently due entirely to the endothermic character of the gas, and not to its high proportion of carbon. Gases with an equal proportion of carbon have only a tithe of its illuminating power, and any admixture with a gas capable of retarding the splitting up of the acetylene molecule until its combination with the oxygen of the air, reduces it to the value of ordinary illuminating gas.

Theories of luminosity are here somewhat out of place, but the student cannot do better than read up Prof. Lewes on this subject, especially in his late work on acetylene. It is one which cannot well be compressed into a small compass.

When burnt under the most perfect conditions acetylene gives a candle power per cubic foot of 48, but in practice, owing to the difficulties in using large burners, 36 candle-power would be considered good.

One of the most noticeable properties of gas flames is the reduction in illuminating value of the gas with any decrease in size of the flame. Acetylene is no exception to this rule, but owing to its very high efficiency the smallest flame appears brilliant, a burner passing out quarter of a cubic foot per hour giving a light of nearly three candles.

The following table is given by Lewes as the result of a trial of a series of "Naphey" burners. With the latest makes of burners somewhat better average figures could be obtained, especially toward the higher end of the series.

Gas consumed per hour.		Candles per cubic feet.
·15 cub. ft.	. . .	5·3
·27 ,,	. . .	11·8
·40 ,,	. . .	20·0
·65 ,,	. . .	26·6
·70 ,,	. . .	32·8
1·00 ,,	. . .	34·0

The "record" for burners of the ordinary size in use without any special precautions to obtain absolutely pure gas is under 18 candle-power for the half-cubic-foot burner, and 30 for the three-quarter-cubic-foot.

Probably the greatest advantages offered by acetylene are seen from the hygienic point of view. In freedom from irritating and destructive fumes, and from vitiation or heating of the air, it stands above all other illuminants, with the exception of electricity.

Theoretically the incandescent mantle uses slightly less oxygen for an equivalent candle power, but in practice it takes far more when used for house lighting, owing to the difficulty in keeping the incandescent mantle up to its standard, and the excessive size of each unit which makes economy of illumination impossible.

Comparing acetylene with the average coal gas used in the ordinary flat flame burner, it consumes less than one-seventh the amount of oxygen and gives off one-eighth the heat, as shown in the following table:

	Cubic feet.	Candle power.	Oxygen consumed.	Carbon dioxide.	Heat (calories).
Acetylene	1	32	2·5	2	320
Coal Gas	16	32	18·5	12·2	2528

But the greatest gain is to be found in the absence of any irritating effect upon the eyes, probably due to the extremely near approach of the acetylene flame to the colour of sunlight.

This is a point which has not received the attention it deserves, probably because until the advent of acetylene all artificial illuminants were found about equally trying to the sight, or for the reason that, being a daily trouble, we had become so used to its evil effects as to forget them.

Munsterberg gives the following table showing a comparison of the ordinary artificial illuminants with the light of the sun:

	Spectrum.				
	Red.	Yellow.	Green.	Blue.	Violet.
Sun	1	1	1	1	1
Electricity	1·48	1	0·62	0·91	0·17
Coal Gas...	4·07	1	0·47	1·27	0·15
Incandescent.........	0·37	0·90	4·30	0·74	0 83
Acetylene...	1·83	1·02	0·76	1·94	1·07
Acetylene with air ...	1·03	1·02	0·71	1·46	1·07

Another result of its very near approach to the colour of sunlight is that tints and shades are easily distinguishable, and of practically the same effect as in daylight.

To photographers the high actinic properties of the flame have been known for some time, and in colour photography it is the only artificial illuminant that can be used with any great success.

Its actinic properties were determined by W. H. Walmsley, who gives the following list of the times required for a full exposure of a standard plate with different sources of light.

Sunlight	1 second.
Acetylene	3 ,,
Diffused daylight reflected from a mirror	12 ,,
Incandescent	24 ,,
Coal gas or oil lamp . . .	240 ,,

For projection purposes its high luminosity and penetrative power place it next to limelight.

The very high temperature of the acetylene Bunsen flame gives it some value in the laboratory, and it has also been used for "incandescent" lighting, but the difficulty in designing a burner for this purpose that does not "light back" has prevented much interest being taken in these experiments. An illuminating value of 130 candles per cubic foot is claimed for the acetylene incandescent with large burners.

BURNERS.

One of the difficulties in the use of acetylene that caused some trouble in the earlier stages of the industry was the tendency of the gas to form a deposit of carbon upon the burner tip, which distorted the flame and caused smoking.

Although it may be possible for smoking to result from a large percentage of polymerisation products in the gas without distortion of the flame, yet in practice it is the distortion of the flame alone that is the immediate cause, whether it is due to impure gas, accidental choking of the burner orifice, or turning down the light.

Acetylene requires a larger proportion of air than ordinary gas for complete combustion, to obtain which it is necessary to make use of a very thin flame with any burner consuming more than $\frac{1}{4}$ cub. ft. per hour. The single-jet "rat-tail" flame is liable to smoke with any consumption over one-fourth of a cubic foot.

To obtain a sufficiently thin flame it

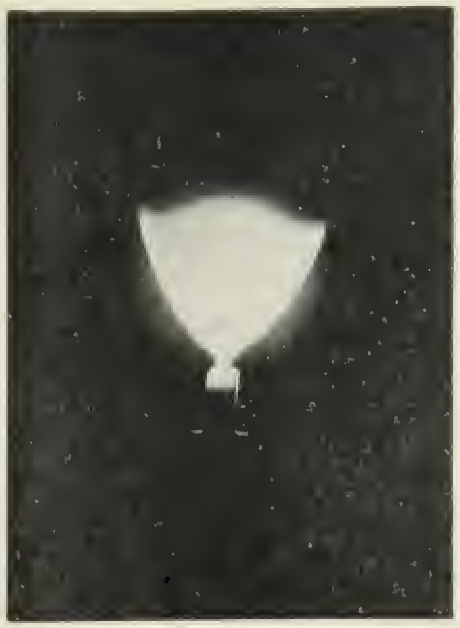

FIG. 24.—FLAME WITH JETS AT AN ANGLE OF 90°.

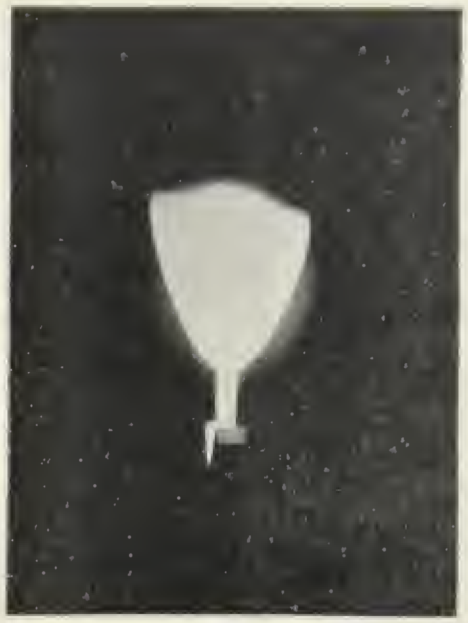

FIG. 25.—FLAME WITH JETS AT AN ANGLE LESS THAN 90°.

is necessary to make use of the "union jet" or of two separate jets, the flames from which splay out against one another. A burner with a sufficiently thin slit would too easily become choked by dust, and one with a series of fine holes, while being partly liable to the same objection, would in any case be too expensive for ordinary use.

To appreciate the causes of smoking it is necessary to note first of all the cases in which distortion of the flame does not lead to smoking. Where the jets are thrown out of alignment only by the warping of the burner or any other cause, the flame does not smoke if the burner is not of larger capacity than the ordinary "half-foot"; and if the pressure of gas is sufficient a still larger flame may become considerably distorted without smoking.

So long as the two jets of the same size and pressure can, when separated, obtain sufficient air for complete combustion, they will be safe in any relative position, but if either jet is reduced in

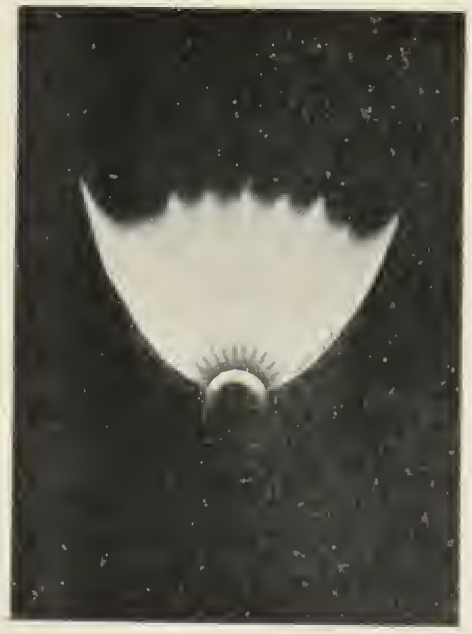

FIG. 26.—FLAME FROM "SCHWARZ" LARGE BURNER.

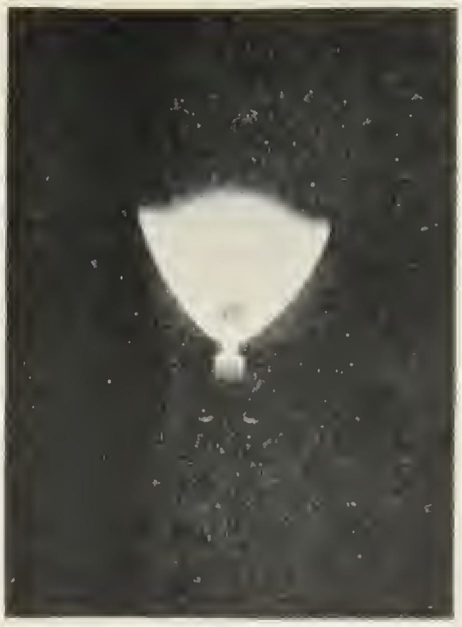

FIG. 27.—FLAME AT HIGHER THAN THEORETICALLY CORRECT PRESSURE.

size or in stiffness (pressure), it is more than likely to cause a thickening of some portion of the double flame and so prevent a sufficient admixture of air.

With large flames, where each separate jet is too large to burn properly by itself, any distortion will cause smoking, and a low pressure of gas will have the same effect, especially in a draught, by allowing the sides of the flame to curl inwards.

The "Bray" type of burner will also smoke when the pressure is too high, and for this reason cannot well be used where the gas pressure is liable to vary.

The "rat-tail" flame, although comparatively thick, can take in sufficient air owing to its greater length, but with the flat flame it is necessary that all portions should be stiff and thin, when burning more than a few litres per hour.

The causes of smoking with large flames may be, therefore, any form of distortion of the flame or insufficient gas pressure, and with small flames, distortion which causes lack of stiffness in some portion of the flame.

The latter is usually brought about by a deposit of carbon on the burner tip, obstructing the jet and causing a lack of pressure where it meets the opposing jet. The same result is sometimes caused by a particle of dust or by moisture or tar in the gas.

The principal aim therefore in designing acetylene burners is to prevent this deposit of carbon. Up to the present it has been found impossible to attain any great success with any form of burner without the help of the generator maker; none of them appear to withstand the effects of impure and moist gas, but with properly purified and dried gas the best forms undoubtedly give thoroughly satisfactory results.

The burners made by Schwarz or Stadelmann with arms and base cut from one piece of steatite, are deservedly the favourites both with acetylene firms and the public.

Made in this way, the arms cannot warp and throw the jets out of alignment, and once having found the most satisfactory angle of impingement and distance apart of the orifices, all burners can be made exactly alike.

Steatite is considered the most satisfactory material for burner tips, as it retards the deposition of carbon better than any other material that could be used, and should a small deposit be formed owing to a low pressure of gas, it will burn away from the steatite on the pressure being increased.

Other materials have been tried, and with some success, on which the deposit of carbon is not retarded so much as altered in character. The "Rubis" burner has the tips made of a highly polished stone from which the carbon can be wiped off without much trouble, and other burners have thin metal plates over the steatite or over a metal tip (Fig. 22).

The deposit on these burners is not so likely to grow to the extent of obstructing the jet; and further experiments with this type, using thoroughly dry gas without contamination from benzene or other oil vapours, might lead to replacing steatite for many purposes.

As well as the deposit of carbon on the outside of steatite burners, a bad gas will cause it to penetrate within the steatite itself, probably owing to the benzene and other vapours soaking into the material and there splitting up under the influence of the heat. When this takes place the burner cannot be cleaned, and must either be thrown away or reburnt in a kiln. The hot, carbon-infected steatite appears to have a decomposing influence on the acetylene passing over it and starts a further growth of carbon almost immediately.

To prevent the decomposition of the gas by the heated burner tip Bullier introduced the Bunsen principle of causing the jet of gas to suck in a portion of air before it comes into contact with the flame. By this means, while there is insufficient time for the air to mingle with the gas, it forms a kind of sheath for the jet and prevents more or less its contact with the heated steatite as well as cools the tip.

A burner of this type, with the two jets separated at some distance, is the one universally accepted as the correct form for acetylene lighting. The separation of the jets has the effect of removing the body of the flame to some distance, and therefore keeping the tips cooler, as well as preventing as far as possible the contact between the flame and the steatite.

In the manufacture of this type of burner there are several variations possible. Neglecting the form of tip, which is at present more or less empirical, and the material used, the two principal variations are in the distance apart of the gas orifices and the angle at which the jets meet.

If the main object in the design of a burner be to obtain the maximum convenience and lasting properties with the minimum loss in theoretical efficiency, the most satisfactory appears to be that passing from 18 to 22 litres per hour, having the small gas orifices within the burner tip $\frac{3}{4}$ inch apart, with the jets meeting at an angle of 90°, and using a pressure of not less than $2\frac{1}{2}$ inches water column (Fig. 28).

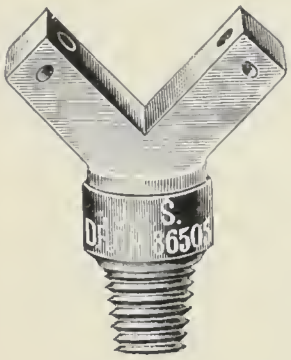

FIG. 28.—"SCHWARZ" "ALL-STEATITE" BURNER.

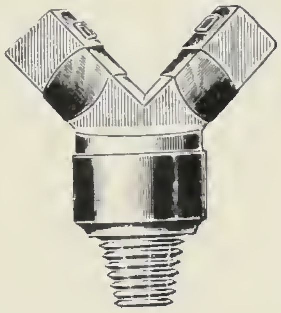

FIG. 29.—"BILWILLER" BURNER (WITH METAL PLATE)

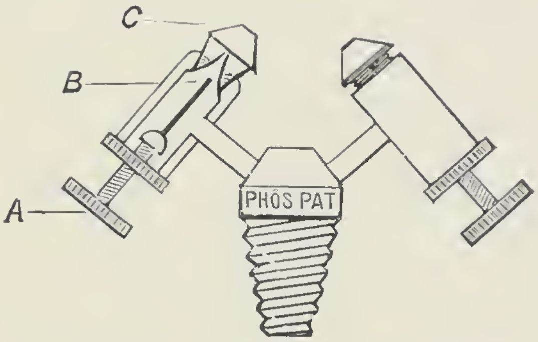

FIG. 30.—"PHÔS" "SELF-CLEANING" BURNER.

Burners of larger capacity may be made with a much wider opening between the jets, and if it be desired to use a higher pressure than $2\frac{1}{2}$ inches. the angle between the jets may be reduced to less than 90° with advantage.

The difference in the shape of the flame caused by the change of angle is well shown in Figs. 24 and 25, though the pressure of gas was not increased as it should have been for the burner with the smaller angle (Fig. 25).

The ordinary "Bray" type of burner in half and three-quarter foot and even in larger sizes is not to be despised for acetylene in situations where the flames are under constant observation, such as in a factory or in shops, provided that the gas is purified, and *thoroughly dry*, and is produced at a low temperature.

With good gas these burners will last a considerable time, and if the first signs of distortion of the flame are seen and the burner replaced, the smoke trouble need not be feared.

It is found to be difficult to use satisfactorily burners passing more than 1 cubic foot per hour, owing to the fact that any kind of distortion of the flame or a drop in pressure is liable to cause smoking, especially if there is any draught.

To overcome this difficulty where a large flame is required Messrs. Schwarz have designed a burner (Fig. 26) with a series of fine holes and working on the Bullier principle, which is very satisfactory with a pressure of about 4 inches water column, or lower if there is no draught.

When using a low pressure in a draughty place, the flame is apt to pass below the outer orifice, and what is known as " lighting back " in a Bunsen burner takes place and soon fills up the tip with carbon.

For a large flame for temporary use the ordinary " Bray " will be found very useful, provided the gas is pure and dry.

While on the subject of burners it is necessary to warn the user against a low or variable pressure of gas. This is a fruitful cause of " carbonised " burners. A pressure of 3 inches in the main pipes is none too much for ordinary lighting purposes, and if this is too high for the burner in use, the tap is always at hand for regulating it for each flame, whereas a low pressure or one liable to periods of depression cannot be remedied without altering the apparatus.

For this reason a gas bell that can be weighted for any pressure should be part of all acetylene installations, whether it is used for storage of the gas or as a regulator.

Fig. 27 shows an ordinary Schwarz burner at a pressure somewhat above that at which the flame gives the greatest illuminating value, but which will keep it free from carbonisation, even with a somewhat impure gas.

To overcome the difficulty in the case of lamps or other small generators where it is almost out of the question to use a purifier, or to make certain that the generation shall take place at a low temperature, the " Phôs " Acetylene Company have put on the market a burner (Fig. 30), containing within the arms small wires which can be pushed forward through the gas orifice by means of the screws, the heads of which are shown at rear of the arms. This frees the gas passage, and if the carbon is wiped off the tip as well the burner may go on working.

The " Phôs " burners should also be of advantage in a very dusty atmosphere, where they would be liable to have the orifices choked with dust when not burning.

To overcome the difficulty in using metal arms the " Phôs " Company make them thin and of soft metal where joined on to the stem, so that they may be bent back into position by the fingers when warped out of alignment.

Another way to overcome the troubles of warping is to prevent it entirely by making the arms of thick and solid metal, as in the " Rubis " and other burners.

In using acetylene in the " atmospheric " or " Bunsen " burner, care has to be taken in keeping the size of the flame orifice below that at which the mixture of air and gas will propagate the flame in the tube. The table given in Chapter II. will be found useful for this purpose.

Although these sizes may be increased, owing to the velocity of the mixture passing through, it is unwise to do so for cooking or other heating purposes where the burner is not under constant observation. A burner that has " lit back " is apt to become choked with soot, and then divert the flame and cause smoking.

Lighting back may be caused by a momentary drop in pressure when the flame orifice is too large, or by any increase in the quantity of air sucked in by the gas when the size of the orifice is proportioned too closely to the mixture in use.

CHAPTER VII.

SOME USES OF ACETYLENE.

THE principal economical use for acetylene is in the lighting of country houses and villages where there is insufficient consumption to make a coal-gas plant profitable.

The great advantage that coal gas has at present is in the direction of cooking and heating, and it is probable that this will always give it the preference where the two gases come into competition for lighting small towns.

On the other hand, acetylene has the advantage over comparatively small installations of electricity for town lighting, and for house lighting it will always compare favourably with paraffin.

The hygienic properties of acetylene lighting place it above all other illuminants, not even excepting electricity, for although the latter has the advantage of not fouling the air in the slightest, yet it is lacking in the purity of colour that makes acetylene so harmless to the eyesight.

When there is added to this the æsthetic considerations of preserving, while artificially illuminated, the true colouring of all decorations and paintings, there is ample argument for the use of acetylene, even in large towns.

Among the special uses of acetylene we may put all cases where the heat or the products of combustion of coal gas are a source of inconvenience, and incandescent mantles or electricity cannot be used; all factories, shops, picture galleries, etc., where it is necessary to examine or use colours by artificial light, photographic studios or printing rooms, especially where colour photography is done, and many other purposes, even in the midst of districts supplied by both coal gas and electricity.

One of the most noticeable advantages of acetylene is the portability of the apparatus, which opens at once a large field for its use, and may be roughly stated as giving it all the convenience of paraffin.

Wherever paraffin is used acetylene can take its place, and in many cases with overwhelming advantages. For lighthouses, lightships, signalling, mining, outdoor engineering, and contractors' work, etc., its steadiness, brilliancy, and " penetration " make it far superior to oil.

In Germany a mixture of oil gas and acetylene is in use for train lighting, and in London one of the principal omnibus companies is using it in place of oil lamps for lighting their 'buses.

For heating and cooking purposes it offers no advantages over coal gas, except that it can be used where the latter is unobtainable. Owing to the small demand, the manufacture of acetylene gas stoves is still undeveloped to any extent; but there are no technical difficulties in the way, and when they are supplied at a reasonable price, it is probable that cooking-stoves will be part of most acetylene installations for house lighting.

The heat from acetylene is only about twice that of coal gas for equal volumes, which brings its cost for this purpose about four to eight times that of the latter.

COST OF ACETYLENE LIGHTING.

In order to arrive at an idea of the cost of acetylene lighting, it is necessary to make use of some standard of comparison. The least variable form of lighting, and the one with which we are most familiar, both in regard to its use and cost, is that of coal gas burnt in the flat flame burner.

The "Argand" is useless for this purpose, and the standard "Argand" worse. Very few people know anything of the cost of paraffin, and the average lighting value of the incandescent mantle in private houses is quite an unknown quantity. Almost the same objections apply to electricity, so we are perforce thrown back upon our old friends, coal-gas and "Bray" burners, which, after all, are vastly in excess of any other form of illumination.

Without risking any injustice to coal-gas and flat flame burners, we may put down their average lighting value in Great Britain as 2 "candles" per cubic foot. 2·44 "candles" is the maximum for burners passing 7½ cubic feet of 16 candle-power gas.

With acetylene, which is hardly out of the experimental stage, it would be obviously incorrect to bring into the calculations old types or badly designed burners. Against the coal-gas burners we can only place some up-to-date form of acetylene burner, such as the "Schwarz" 12½, 18, and 22 litre, and in giving the average value of these as 30 "candles" per cubic foot, ample allowance is made for the use of the smaller sizes, and also for impure gas.

This makes acetylene fifteen times the value of coal gas.

If instead of the average we take the maximum for the 7½ cub. ft. coal gas and the 1 cub. ft. acetylene burners respectively, we obtain 16·39, and if we allow for the superior penetration, steadiness, and clearness of illumination of the acetylene flame, we can still increase these figures to a considerable extent, Dr. Tate giving the comparative efficiency as more than 20 to 1.

Taking carbide at its present price of 16*s.* per cwt.* at the works, and adding 25 per cent. for the agent's profit and 30 per cent. for carriage, we obtain an average cost to the consumer of 25*s.* per cwt.

This carbide is sold on a guarantee of 5 cub. ft. of gas per pound when packed at the factory, but to make allowance for waste, we will reduce this by over 10 per cent., obtaining, as the prime cost of the gas, 50*s.* per 1,000 cub. ft.; to which must be added the cost of purifying material and extra cost of burners, which should not be more than 2*s.* 6*d.* per 1,000 cub. ft.; and if we take a moderate size installation as a standard, another 2*s.* 6*d.* added for depreciation and repairs should cover all expenses.

This not by any means favourable estimate gives the cost of acetylene as 55*s.* per 1,000 cub. ft., and at the low comparative efficiency of 15 to 1 as equal to coal gas at 3*s.* 8*d.* per 1,000.

By reducing the cost of the carbide and the burners, and increasing the yield of gas, none of which is at all out of the question, we can, under favourable circumstances, approach the figures which have been so much objected to by some of the nervous friends of the industry, and even go beyond them, if we take a more favourable but still perfectly permissible view of the comparative illuminating values of the two gases.

---

* Now 13*s.* per cwt.

The facts that a very imperfectly designed generator may not yield the 4½ cub. ft. per pound of carbide, and that whenever the quality of illumination is improved there is always a demand for an increased quantity, cannot affect these figures although they may the *average* tangible results.

CHAPTER VIII.

THE FITTING UP AND CARE OF AN ACETYLENE INSTALLATION.

HAVING chosen the type of apparatus best suited to the requirements of the situation, the next consideration is that of the shed or outhouse to contain it. If one of the non-automatic types is taken, the size of the gasholder may require that, for the sake of economy, it should be placed outside the building, and in this case all taps and stop-cocks should be brought inside to prevent undue corrosion.

To allow of a free escape of gas arising from a leak or when attending to the apparatus, the shed should be well ventilated, arrangements being made for securing a current of air through the building, either by having a good-sized opening, not too much above the floor level at each end of the building, or a number of smaller openings at about the floor level and in the roof. A small shed is more conveniently ventilated by using a half-door only, leaving the upper half free.

The shed should be sufficiently large to contain a drum of carbide as well as the apparatus, so that it may not be necessary to carry exposed carbide through rain when charging.

The next points on which a little care and thought are well worth the trouble are those of water supply and removal of the residue.

Where the water runs into the generators as required during the production of gas, a separate tank should be used in the generator shed, and may either be kept full by means of a ball valve or filled each time the apparatus is charged. The pipes may then be prevented from freezing either by the use of calcium chloride in the tank or by emptying them at night, and the fittings will also be relieved of the strain put upon them by a high pressure of water.

The gasholder tank is sometimes used for this purpose, but it is at best a very awkward and unsatisfactory method. In this case it should be fitted with a ball valve for maintaining the water level.

In any apparatus of the "water-in-excess" class the residue ought to exist only in the form of sludge, and be removable by simply running it off through a cock, and the grids or carbide cages should require no cleaning beyond the removal of pieces of crust or slag.

In this case the sludge may be drawn off either into a pail, or by means of a pipe directly into the pit prepared to receive the lime. With a closed-in generator, such as the "water-to-carbide" type, this sludge pipe should not be connected to the generators, but merely brought up to the sludge cock by a bend or "tee," so as not to cause syphoning if the lime is run off while the generator is closed.

The lime pit may be simply a hole in the ground that will allow the water to percolate away, or where this would be objectionable from any cause the sludge may be run directly into the drains if they are flushed immediately afterwards so as to clear the lime out of the syphons and small pipes.

With the "carbide-in-excess" class of generator, the lime is removed in a semi-solid condition, and may even be obtained almost dry by regulating the amount of water according to the quantity of carbide in use. This form of residue may be simply placed in a heap in some convenient corner of the kitchen garden, and is then useful for sprinkling over refuse heaps as a disinfectant, and in some districts is a valuable addition to the soil. It also makes very satisfactory mortar for rough building. It ought not to be placed in a closed-in shed, as if the charge contained any very slow-acting carbide, such as is sometimes found, it may be thrown away with the residue and cause an accumulation of gas.

In fitting up the plant, care should be taken to properly drain all pipes and apparatus that carry moist gas, and to provide small cocks in a suitable position for drawing off the condensed water. By a proper arrangement of the plant one, or at most two cocks will be found sufficient for this purpose.

To prevent freezing in winter, a small stove may be placed outside the generator house, and the flue or hot-water pipes conducted through it; but in the English climate this is hardly necessary—a little thought in fitting up and a little attention in cold weather should be all that is required (see Chap. IV.).

Having satisfactorily settled the question of type and arrangement of the plant, and ascertained that the gas will be delivered into the pipes properly purified and dried, the next consideration is the piping and fittings.

As acetylene does not carry with it any naphthaline or heavy hydrocarbon vapours, such as are always present with coal or oil gas, it is necessary that all pipes and fittings should be far sounder and more carefully put up than appears to be the general custom with coal gas. There is no difficulty whatever in this, and the pipe work that is required for acetylene is only that which is expected of any honest gasfitter.

The brass fittings and all taps must be of good quality or specially made for acetylene. The cheap brass work on the market could not even be used for coal gas were it not that we have become so accustomed to its odour that small leaks are unnoticed.

All cocks used for acetylene should be made of good metal and have long plugs, especially those about the apparatus, which should be made of gunmetal or other hard composition.

Swing fittings and ball joints are at best liable to become leaky, and consequently unsuitable for acetylene unless of thoroughly good workmanship and heavily built. A special ball joint is made for this gas with an india-rubber connection between the cup and ball, which is very satisfactory if the rubber is changed when it begins to "perish."

The pipes used for acetylene are roughly about half the diameter of those used for coal gas, but should be of sufficient size to pass all the gas required when all lights are burning without any noticeable difference in pressure between the nearest and the farthest burners, while the pipes connected with the fittings may be as small as can be obtained, the use of one-quarter-inch brass piping making a very good method of connecting up the fittings where the pipes have to be placed outside the plaster.

CONCLUSION.

While these articles have been written mainly for the use of those engaged in the industry, I have endeavoured to make them sufficiently clear to the untechnical to enable the purchaser of an acetylene generator not only to choose the one most suited to his requirements, but also to make use of it in the most satisfactory manner.

The necessity for condensation has made this a matter of some difficulty, and is also pleaded as an excuse for the omission of much that is of interest and importance.

It will be seen from a study of the chapters on acetylene production that if the conclusions there arrived at are accepted, a very large portion of the apparatus at present on the market must be considered obsolete. But this is almost a necessity in any new industry, and the time inevitably comes when the accumulated knowledge and experience of the trade can be expressed in more or less definite form, outside of which imperfection or failure is certain.

Permanent success in a new industry of this character is only to be obtained by the manufacturer who is always ready for any improvement, even when it revolutionizes his present methods.

I desire to express my thanks to those firms who have so kindly assisted me with illustrations, especially to Mr. L. Wiener for photos of acetylene flames; and also to acknowledge my indebtedness to that very complete work on acetylene by Prof. V. B. Lewes for many facts and tables included in these articles.

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APPENDIX.

AUTOMATIC "CARBIDE-TO-WATER" APPARATUS.

THE above sub-type of generator was touched upon very lightly in the chapter on Generator Design, owing to the impossibility of dealing with its many forms in the space at disposal, as well as to its more experimental character, and the fact that either the complicated mechanism employed or absence of economy in gas production places it among the apparatus for special use rather than for ordinary lighting purposes.

Where the risk of temporary failure is not a matter of importance, or strict economy is not required, it offers the advantage of producing a large amount of cool, easily purified gas from a very small apparatus.

There are, of course, innumerable ways in which small quantities of carbide can be automatically dropped into water by the fall of the gas bell, but to be of any practical use they must be

1. Absolutely simple, reliable, and easy to repair and adjust. After which, the most important points are:—
2. Sealing the carbide from the air.
3. Regulation of the amount of carbide fed in by mechanism.
4. The use of as large carbide as possible.
5. The ability to charge the generator without loss of gas (unless the holder is very small).
6. Sealing the carbide from the moisture in the apparatus (unless the holder is comparatively large).

Roughly speaking, there are two methods by which these objects may be more or less conveniently accomplished; one requiring "granulated" carbide and permitting of the use of a very small gasholder, and the other using any size of carbide and necessitating a larger holder.

The simplest form of the first method probably consists in the use of a cone valve at the base of the carbide hopper, depressed by the fall of the bell and returned on the rise of the bell by a weighted lever—a spring is undesirable.

As an additional safeguard against too large a fall of carbide, a second valve may be used inside the hopper, which tends to close the opening when depressed. Both these valves may be mounted on the same rod, and the space between the two will roughly represent the amount of carbide fed in at each fall of the "bell."

If the gasholder is separate from the generating apparatus, charging without loss of gas will present no difficulty; but the sealing of the carbide from the air will necessitate the use of a "stuffing box" for the valve rod to pass through, or a flexible diaphragm.

In the other form of apparatus the

carbide is usually held in separate compartments, which are opened one at a time and the contents discharged into the water, or a screw or other means is used to feed it towards the opening in the water tank.

With this method the carbide may be protected from moisture by soaking it in paraffin, as the larger size of gasholder and the slow or intermittent carbide feed gives sufficient margin of time for the water to penetrate the protective film before the reserve of gas is used up or too much carbide is fed in.

It is in this latter form of apparatus that developments are likely to take place if this type is ever to be used for ordinary positions.

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